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Circular economy modelling to accelerate the transition of ports into self-sustainable ports: a case study in Copenhagen-Malmö Port (CMP)

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CIRCULAR ECONOMY MODELLING TO ACCELERATE THE TRANSITION OF PORTS INTO SELF-SUSTAINABLE PORTS

A Case Study in Copenhagen-Malmö Port (CMP)

By

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Declaration

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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Abstract

Title of Dissertation: **Circular Economy modelling to accelerate the transition of ports into self-sustainable energy ports – A case study in Copenhagen-Malmo Port (CMP)**

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Sustainability has been recently the main focus of developments in all industries. Sustainable relation between ports and ships is one of the emerging factor in maritime industry. Apart from city-port framework, there is hardly an independent mechanism for port sustainable development, specifically within the energy context. In last years, ship waste management and reduction of the negative externalities of the ships, have been among the priorities of the European ports. To address these issues, circular economy (CE) application in ports has gained a significant attention.

This research will investigate the application of a CE model in the Copenhagen-Malmö Port, as a case study. The innovative State-of-Art model introduced in this research, deals with the feasibility of a circular economy loop to give added value to the large amount of the waste in Copenhagen-Malmö Port. The proposed model includes elements like waste management, port-owned biogas plant and cold ironing to close the waste-to-energy loop from/to ships. For different amounts of the wastes, three scenarios are assumed and investigated in Copenhagen-Malmö Port. Each scenario is followed with a cost-benefit analysis to show the feasibility of the CE model. The research concludes with the feasibility of the CE approach for the Copenhagen-Malmo Port and further analyse the benefits and costs of establishment such model for all scenarios.

Keywords: Seaport, ship, waste management, circular economy, green biogas power plant, clean energy, shore-to-ship power supply, self-sustainability.

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List of Abbreviations and Acronyms

AE	Auxiliary Engine
CE	Circular Economy
CMP	Copenhagen-Malmö Port
ESPO	The European Sea Ports Organization
GHG	Greenhouse Gases
HFO	Heavy Fuel Oil
HELCOM	Baltic Marine Environment Protection Commission - Helsinki Commission
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
IE	Industrial Ecology
ISO	International Organization for Standardization
MARPOL	International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto.
MDO	Marine Diesel Oil
MEPC	Marine Environment Protection Committee
MEM	Maritime Energy Management
MGO	Marine Gas Oil
MSc	Master of Science
NOx	Nitrogen Oxides
SCR	Selective Catalytic Reduction
SOx	Sulphur dioxides
UN	United Nation
UNCTAD	United Nations Conference on Trade and Development
UNFCCC	United Nation Framework Convention on Climate Change
WMU	World Maritime University

1. Introduction

1.1 Background

Humans are altering the planet at an increasing rate in particularly with significant environmental impacts (Waters, Zalasiewicz, Summerhayes, & Barnosky, 2016). Since the beginning of the industrial revolution, humans have contributed unnatural sources of greenhouse gases into the system, with the consequence of unbalanced system. Global impact of human activities resulted in anthropogenic climate change. To avoid a shift from the environmental stable period in Earth's history, the concept of planetary boundaries is developed, which should not be crossed to have a sustainable natural ecosystem on Earth (Stockholm Resilience Centre, 2017).

Port-cities have always undergone wide changes, after the industrial revolutions. They thrived since the revolutions depended considerably upon the trade of cargo, passenger, and fishing (Jansen, 2016). Among all areas on the Earth, seaports are in vulnerable places for climate changes impacts: sea level rise at coasts or flooding at mouth of rivers. They play a crucial role for economies at local and international level (Becker, Inoue, Fischer, & Schwegler, 2011).

Shipping to seaports, among various types of transportation industries, has an essential contribution to the world economy since more than 90% of the world's trade is carried by sea (World Trade Organization, 2010). Transportation which includes shipping, has been listed as one of the four cornerstones of globalization, along with communications, international standardization, and trade liberalization (Kumar & Hoffmann, 2002). However, it accounted for approximately 3.1% of the annual global CO2 emission (IMO, 2015). Air pollution endangers the human life and has many negative impacts on human health, causing substantial economic consequences. The negative externality costs can be compared to other socio-economic costs. The market impacts of air pollution are expected to be substantial economic costs, which are illustrated at the regional level, and to extensive global welfare costs (OECD, 2017).

Drivers for enhancing ports' developments, sustainable shipping, and secured coastal resources. can be categorized in legislative and non-legislative drivers. The legislative drivers could be international regulations from International Maritime Organization (IMO) for international shipping such as International Convention for the Protection of Pollution from Ships 1973 as modified by the Protocol 1978, (MARPOL 73/78) covering prevention of pollution of the marine environment by ships from operational or accidental causes (IMO, 2017). While many drivers are in the context of 'command and control' nature, there are non-legislative drivers such as increase in fuel oil price, energy resource scarcity and economic instruments. The economic measures may provide more flexibility for environment polluters like ships. An example of non-legislative driver is land-based cold ironing in ports to provide electricity to ships at lower cost than on-board generated electrical power. One character of industrial societies has been the greater efficiency with which they turn energy into the economic output as industrialization proceeds (Watson, Ekins, & Bradshaw, 2015). Furthermore, there are other new approaches such as the circular economy model to address negative externalities and impacts of shipping.

CE at ports and shipping is more necessary since they are one of the sources of both negative and positive externalities affecting the public well-being locally and globally accordingly. As the products are in the global closed loop, wastes can be traded as well worldwide. Ports usually put some added value on all kinds of raw materials and products, therefore it can be simulated for waste as well. It is even more profitable to execute these activities in a port area because of industrial parks, clustering activities and mega cities in the proximity of ports (Kuipers & Jong, 2015). A port authority can provide platforms for start-ups to motivate innovation in industrial areas of the ports. In future, there will be a greater shift from the global closed loops to regional loops among ports which results in an increase in competitiveness (Kuipers & Jong, 2015). The port expansion along with the relocation of the industry from inland to the coast due to globalization represents both a challenge and an opportunity for ports and cities. At EU level, besides principles set by the European strategy for a circular economy, guidelines for port cities could be developed. McKinsey (2012) evaluated that fulfilment of the models would benefit 500 billion euros for the economy. Some port authorities have already been inspired by the use of the circular economy in their strategies.

1.2 Theoretical Framework

In this context, first, the linear economy is briefly explained while the circular model will be enlightened in concept and principles. Furthermore, there will be a brief look at the transition from current linear economy to ideal circular economy. The different types of loops in CE will be discussed while applying the circular economy in ports will be regarded. Finally, a circular economy model, in terms of energy sustainability, will be focused for the port of Copenhagen-Malmö.

Industrial revolution shaped a global form so that the current industrial economy involves combinations of elements such as raw material, knowledge, work, and facilities, to produce goods. It can be divided in two approaches: the linear economy which is dominant, and the circular economy (Greyson, 2007). The world economy has mainly structured based on linear approach in spite of its serious risks (MacArthur, 2014). Current linear economy which is "take-make-waste", structured on the extraction of numerous amount of low price available raw materials and also energy, which is about reaching its planetary boundaries (Wijkman & Rockström, 2012). This model has not only degraded natural sources but has also posed extensive damage to the environment and human health. (See Figure 1).

Figure 1. Linear Economy

In 1966 economist Kenneth Boulding described the circular economy as a model with long-term economic growth, sustainability and zero waste (Greyson, 2007). Circular economy eliminates any waste in every stage of the design, reuse and recycles via an interconnected system and market. It can be interpreted as a cradle-to-cradle approach. (See Figure 2).

Figure 2. Basic circular economy

The circular economy is a generic term for an economy where the concept of waste itself doesn't exist, materials circulating through technical and biological cycles. It aims to give maximum value and eliminate waste by improving the design of materials, products, systems and business models. Circular economy can be defined as "An industrial system that is restorative or regenerative by intention and design. It replaces the end-of-life concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models." (Ellen MacArthur Foundation, 2013, p. 7). Circular economy is structured on three main principles of preserving natural resources, namely optimization of the resource by circulating products, and raising system efficiency by targeting and phasing out negative impacts in design. One of important characteristics of circular economy is systematic thinking**.** The systematic ability to think how elements and parts of a system influence not only each other but also the whole is essential in a circular economy model. Components are regarded in relation to their environmental, economic and social contexts (Ellen MacArthur Foundation, 2015). As many natural resources reach the planetary boundaries, the scarcity of natural raw materials appears to be the main driver for adoption of the circular economy thinking. Drivers such as sustainable development, environmental awareness and competitiveness caused the circular economy concept to gain significant attention too. Furthermore, the application of a circular economy turns to be interesting for companies, due to independence from political tensions and market fluctuations (Kuipers & Jong, 2015). In this regard, some ports are approaching circular economy models to have a transition to sustainable profile. Figure.3 shows the loops of circular economy**.**

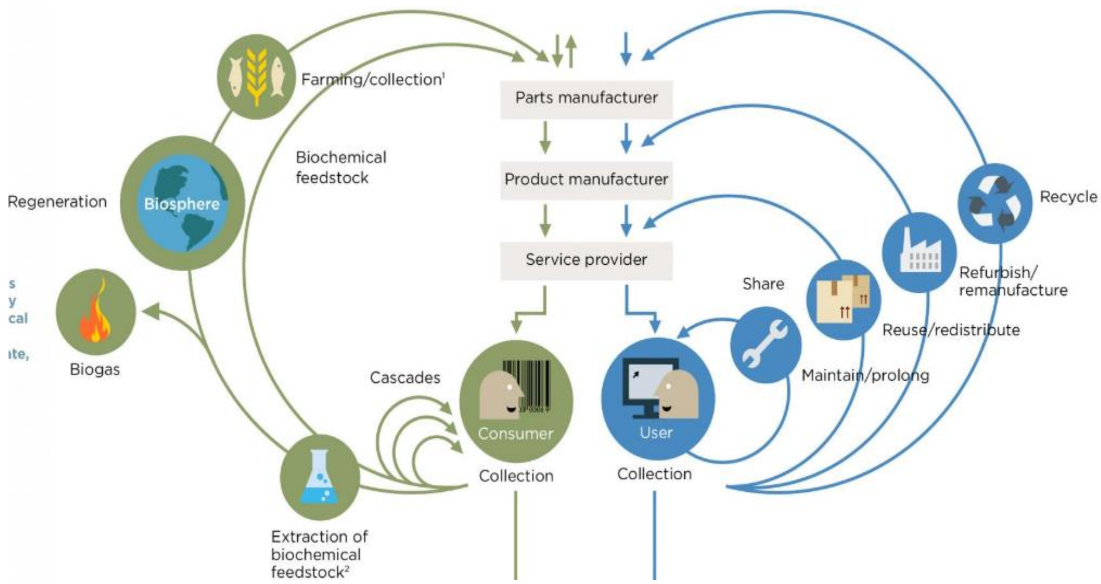


Figure 3. Circular economy loops

Source: ElleMacArthur Foundation (2017)

There are some indicators for the circular economy. Some developed countries such as the OECD and the G8 generally use gross domestic product (GDP) divided by domestic material consumption for natural resource use. In addition, there are other indicators such as recycling rates, the EU resource efficiency scoreboard and the amount of waste per capita or per GDP (Bourguignon, 2016).

Circular Economy: Opportunities and Challenges

Shifting from traditional linear economy towards a closed-loop economy has both economic and environmental logical reasons. It reduces environmental impacts via improved waste-management and also reduction in the use of resources. In addition, it enhances the security of supply of raw materials, as it would mitigate risks associated with price volatility and import dependency. As a result, it increases competitiveness by bringing savings to different businesses and also consumers. Ellen MacArthur Foundation carried out a study in 2015 for EU that shows by 2030, a shift toward more circular economy can decrease net resource spending in the EU by approximate €600 billion every year. In addition, this approach would trigger innovation among different industries due to the need to re-design wastes and products for reuse. Finally, a circular economy strongly supports economic growth and produces job opportunities. It is also estimated that the transition would increase GDP by 1 to 7 percentage points by 2030 (Bourguignon, 2016).

Finance may be considered the main barrier for businesses in transition toward circular economy. The costs of "green" innovations in infrastructure, R&D section, investments for new business models, IT improvement, public waste management and the adoption of more sustainable practices are considerable. Another challenge is the lack of skills in the workforce and manpower. Shortage of technical skills can be mainly problematic for the design stage of products when circularity in mind is vital (Bourguignon, 2016). There is a big problem in the systematic shift to a circular economy as many business models and consumer behaviours have been shaped on a linear model. Another challenge can be governance and policy as this demands actions at multi-levels (Bourguignon, 2016). However, there are still other related problems to the application of circular economy such as lack of indicators that captures all the main elements of the closed loops-the circular economy along the lifecycle of raw materials and products.

1.3 Problem Statement

The world is reaching the ending limits of natural resources and Earth's capacity to intake waste and pollution (European Commission, 2017). Under the planetary boundary concept, nine global priorities identified in relation to human-induced changes to the Earth in the anthropogenic era. They control the stability, resilience and ecosystem balance on earth which is interactions between ocean, land and atmosphere. As human activity pushes the earth system beyond planetary boundaries, four of these crossed boundaries endangers the future of humankind on earth (Stockholm Resilience Centre, 2015). Greenhouse Gas (GHG) emissions by human activities have resulted in global warming and climate change (International Panel on Climate Change, 2013). Climate change has been affecting all dimensions of human life, in particular, food security and health issues (FAO, 2008).

Among all human activities, shipping has a wide range of negative externalities on the environment. Particularly in ports, people are under day-and-night activities of the harbours and it is more severe if ports are placed near urban areas of cities (Wilewska & Lindgren, 2016). A cost of an externality is a negative externality that for shipping activities, it can include the social cost (primarily health cost) of vibration and noise pollution, atmospheric pollution, ballast water operation, accidents and port congestion (Ballini, 2013). Furthermore, there is a problem of ship-generated noise from auxiliary engines and machinery used to produce electricity for ship cranes and domestic use. (OECD, 2011). IMO highlighted under its third GHG study, on average shipping accounted for approximately 3.1% of annual global CO_2 emissions between 2007–2012. Maritime CO_2 emissions are predicted to be increased enormously in the future decades between 50%-250% by 2050, in all scenarios (IMO, 2015). However, new regulations within MARPOL on the energy efficiency improvement on shipping have achieved remarkable reductions of CO_2 emissions (Hughes, 2013). Another impact of the shipping industry is ship-generated wastes. The Marine Environment Protection Committee (MEPC) 54 highlighted the significant waste collection in the area of implementing the MARPOL regulations (IMO,2017).

As reported by the European Sea Ports Organization (ESPO) in 2016, the issues such as air quality, energy consumption, noise, ship-generated waste, port waste, and port interaction with local community were among the top 10 environmental priorities of European ports and will be discussed and to some extent within the case study model for

CMP. From 2009, the significance of energy consumption has increased every year so that in 2016, energy consumption became the second priority issue of European ports. In recent years, both the port waste and ship waste have been among the top ten environmental concerns that highlights the importance of waste management in European ports (European Sea Ports Organization, 2016).

1.4 The Objective

The main aim of this study is to investigate and identify a sustainable relation between ships and ports in terms of energy management. This research will evaluate and critically analyse the techno-economic feasibility of a circular economy model for CMP port targeting the UN 2030 Sustainable Development agenda. In particular, Goal 7: clean and affordable energy- with a focus on port and berthed ships; therefore, in this context, collection and then conversion of ship-generated wastes to clean energy are investigated. For this purpose, a closed loop will be established including main elements like ship food-waste and water-waste, biogas green power plant, and finally a shore-to-ship power supply facility. Along with that, the techno-economic barriers, potentials, and drivers for establishing such a circular model at Copenhagen-Malmö Port will be discussed as a case study.

This research will take also in consideration the role of stakeholders' contribution like the human element in collecting wastes and also port authority and municipality in waste management. Through this circular economy model, a bottom up approach will be discussed to implement an Integrated management to achieve a self-sustainable port with secured demands for energy. The importance of this approach is to reduce the environmental impacts of these ships at port, by introduction of clean energy through shore-to-ship electrical power

1.5 Research Question

The aim of this study is to investigate and explore the techno-economic potential of a circular economy approach, involving shore-power-supply, in the port of Copenhagen-Malmö to reduce the emissions and to set up a self-sustainable model in term of energy security.

For this purpose, the main question is: How the circular economy model can support self-sustainability of the ports in term of energy security? To address this question, there are three sub-questions to be answered, as follows:

- What are the barriers and drivers to establish a circular economy model in ports?
- How is the circular economy approach technically feasible for Copenhagen-Malmö Port?
- What are the incentives for the proposed circular economy model in CMP?

1.6 Research Scope and Challenges

The scope of circular economy is broader and different from "Industrial Ecology (IE)" and "Waste Recycling" concepts. Thus neither industrial ecology nor waste recycling will be discussed in this research. Furthermore, the legal framework of Copenhagen-Malmö Port for implementation of the circular economy approach of this research will not be discussed. Therefore, this context is emphasized and limited to the technical feasibility of framing a circular economy model, to mitigate pollution from passenger ships and recirculate the ship's organic solid waste and sewage back to ships in term of energy in Copenhagen's Oceankaj terminal. In this issue, the technical challenges of establishing the model is limited to the Oceankaj cruise terminal.

1.7 Research methodology

There are fundamentally two data sources for this research: primary data and secondary data. Primary data are the ones collected through interviews, and questionnaires. It requires to physically collect the data by meeting persons, over the phone, by email or Skype. The explicit information collected for the research is primary data, while the secondary data is the information collected by others rather than the author (Laycock, Howarth, & Watson, 2016). Table 1 shows the strength and weakness points of each sources of data for this case study. There are data and information in journal articles, books and reports used as secondary data as well as market research and legal directives. They are all about synthesis, analysis and collation of the collected data by other writers.

Table 1 The primary and secondary data collection for this research

Source of data	Strength	Weakness
Primary	- Control over the nature and also the volume of data since it is gathered by the researcher -Many options are available and material are up-to-date for 2016 and 2017	-Data needs to be categorised and analysed carefully
Secondary	-Already huge amount of information and data exists and analysed	Data was marginally related to this case study on CMP

Source: Recaptured and reproduced by author from Laycock et al., (2016)

In order to fulfil the objectives of this study, a combination of the methods has been used. Both quantitative and qualitative approaches have been applied to establish a circular economy model for Copenhagen-Malmö Port (CMP). The main part of the qualitative methodology will be carried out through interviews in two phases with CMP terminal and environmental departments. The first phase was carried out by interviews to receive some general information about CMP environmental and energy policies, while investigating the strategies for the future. The second phase of the interviews was carried out through contacting the CMP Port by email to access the required data about the CMP performance, specifically during 2016. In addition, the Puxin biogas company was also interviewed at this stage to obtain technical specification and price quotations of their products.

The interviews followed a specialized pattern of verbal interaction, initiated for a specific purpose of data collection and focused on some specific content areas (Mishler, 2009). Both phases of the interviews were to some extent similar to questionnaires and the interviewee answers were recorded. Among three different types of interviews: structured, semi-structured and unstructured, the semi-structured interview has been used in this research. It is due to the reason that in this situation, there were fewer predetermined questions and it is more likely to develop as a "guided conversation" according to the willingness of the port interviewees (Walsh & Thornes, 2011). The main advantage of this type of interviews considered in avoiding too much prejudgment. It allowed the questions not be narrowed down in the first phase while giving the opportunity to probe what the interviewee states. It other words, there is more possibility to discover and take advantage of unexpected revealed information (Walsh & Thornes, 2011). However, the accuracy of data was observed by writing down the exact verbal statements in phase one. In the following chapters wherever the data and information of interviews are referred, then it is validated by comparison to the similar cases gained from the literature review. Some of the asked questions during interviews were open-ended, due to the confidential statistics and data of the CMP Port. Furthermore, the question forms in Appendix A is anonymous and the names of the interviewees are confidential too.

A case study as defined by Yin, (2009) is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real life context (Joyner, Rouse, & Glatthorn, 2012). The advantage is that being a small-scale research into CMP and not be solely dependent on already published works, it looks at the whole situation but focuses on the inter-relations. However, the disadvantage is it generates lots of different information since different methods are used by researchers, followed up by different analysis and interpretations. In addition, the IMO, European Maritime Safety Authority (EMSA), EU publications, regional and CMP reports have been referred to. Data collection and literature review will be followed by a SWOT analysis of a port-owned biogas plant and later with cost-benefit analysis of the circular economy modelling for Copenhagen-Malmo Port. Figure.4 illustrates the methodology used within this context.

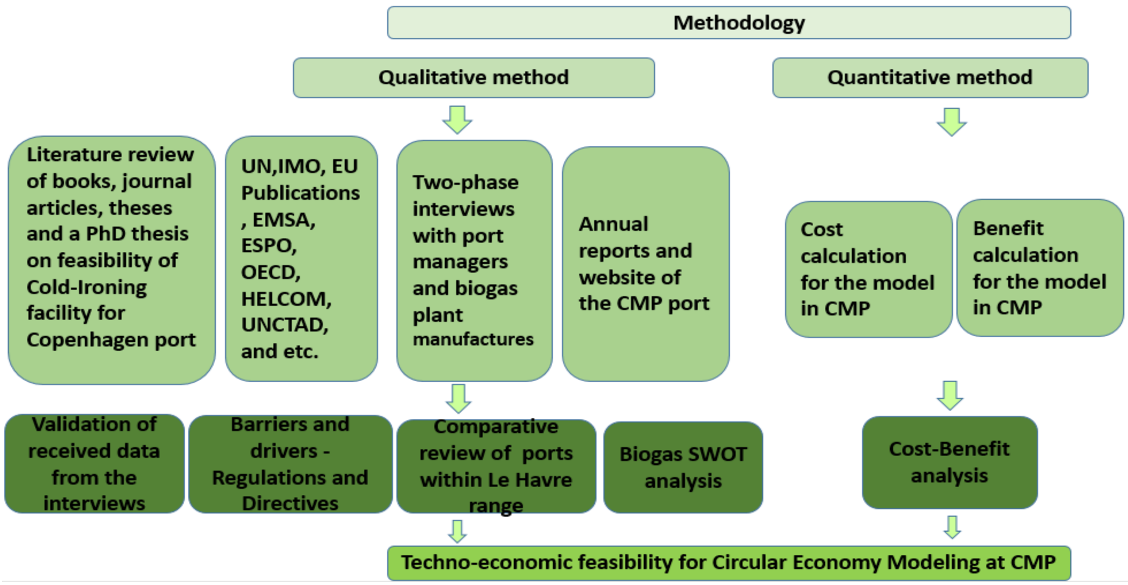


Figure 4. The flow-diagram of the methodology applied for this case study

2. Literature Review

In this chapter, an overview of the ports which have already applied circular economy in their development strategies will be discussed and analysed. Four ports, Amsterdam, Rotterdam, Hamburg and Antwerp within Hamburg-Le Havre range are selected for review and comparison.

The city of Amsterdam as a leading city in environmental issues has “2040 Energy Strategy”. For a structural planning, the city council allowed that citizens, businesses, and organizations to be given the opportunity to share their thoughts. In this context, three pathways of energy savings, maximum use of sustainable energy, and increase the sustainability and efficient utilization of fossil fuels was established (Municipality of Amsterdam, 2010). Some port-cities like Amsterdam stimulating the emergence of innovative circles and places whereas people bring expertise together around problems to turn them into business opportunities (Jansen, 2015).

The Port Authority of Amsterdam has been obliged to a 40% reduction CO_2 by 2025. For this purpose, in the port’s western area, some big wind turbines have already been installed and electricity for ships docked in the port will be provided from shore power supplies instead of their own power supply. The Waste and Energy Company which operates in the port area produces electricity of which almost 47% is sustainable (Municipality of Amsterdam, 2010). According to the Vision2030, the port seeks to become "an innovative hub for energy transition and a circular and bio-based economy" that will produce jobs beside providing economic growth. A bio-based economy means mainly to use renewable energy, biological materials, and industrial raw feedstock. The reason Amsterdam is interested in cultivating a “Bio-economy” comes from the business opportunities for the port. Biomass is bulky raw material, and the port already has terminals to handle it. At the end of the day, the port plans to replace current fossil-fuel cargos with biomass ones (Berger, 2016).

Rotterdam is the largest European cargo port and relies on the import of resources. A huge infrastructure with strong finance drives Rotterdam for innovative business models. As scarcity of resources has become a threat that put a risk at Rotterdam, a circular low carbon economy will secure the economic stability (Bye, Vusse, & Tilborg, 2017). The city of Rotterdam has set up the “2030Roadmap” which includes all stakeholders’ engagement in city activities (Port of Rotterdam, 2016). It involves goals over short, mid and long terms to push circular businesses forward specifically in main economic clusters which are food, clean-tech and the maritime industry. The roadmap contains a mechanism for circular economy communication to share the topics like the policy, real case examples, and benefits for the citizens. To facilitate academic involvement, a link with educational centres was set up (Port of Rotterdam, 2016). Circular economy in Rotterdam includes two phases. In phase.1, between 2016 – 2019, the framework involves short term actions of Embed, Act and Inspire. Appointing a budget to facilitate bottom-up initiatives is an indicator of circular systematic thinking in Rotterdam. According to the Act plan, a taxing system in this phase is supposed to set up for support of circular businesses. Between 2019-2030, phase 2 incorporates learnings while embedding circular economy into the businesses, knowledge centres, and households while providing 3500 to 7000 jobs.

A 0-ton residual waste strategy will be achieved by improving business models in which goods and products after consumption will be shared, repaired to be reused, or sent to some sites for refurbishment. Food waste streams are recaptured for mainly soil fertilizer while wastewater is purified into high quality potable water (Port of Rotterdam, 2016). Additionally, creating a new raw material/recycling valley is considered, based on a circular economy approach, to allow private initiatives for residual waste collection. Bio-LPG Neste plant is the world's first type of Bio-LPG facility located in Rotterdam to replace a portion of fossil fuels without any modifications to current gas facilities and applications such as transport (Lipponen, 2015). Rotterdam eases initiatives to accelerate reaching to the city's goals in the Sustainability Programme and Waste Programme (Bye, Vusse, & Tilborg, 2017).

Hamburg Port Authority (HPA) utilizes circular economy by providing a platform for a wide range of information and support for the customers and companies to make them familiar with the circular economy models. The port authority wants a modal shift, to make every transport mode more sustainable (Hamburg Port Authority, n.d.). Energy transition is a key environmental strategic topic and the HPA is committed to the initiative SmartPost for a reorientation of energy use at the Port of Hamburg (Hamburg Port Authority, 2015). To reduce ship-related emissions along cruise industry growth, the HPA has established a land-based shore-power-supply infrastructure, which supplies power to ships by utilizing a power barge. Ships of the AIDA Sphinx class, have been using the cold ironing since 2014. Hamburg is the first port in Europe to utilize power barges as shore-power facility for ships. Moreover, a converter substation converts the electricity supplied from the electrical grid to 11 kV, 60 Hz electricity and feeds it to the ship. The investment in Altona, is another milestone in Hamburg Port to attract cruise ships (Hamburg Port Authority, 2015). In Hamburg Port, one of the methods to provide energy is enabling owners to use their own self-generated power (Hamburg Port Authority, n.d.). After feasibility assessment by HPA in 2014, it was found that the port's owned biogas plant did not make any economic sense as the biomass from the fermented portion of green waste and grass was insufficient, with a maximum 1,000 tons a year. However, the economic viability is subjected to investigation again (Hamburg Port Authority, 2015). To improve energy efficiency, HPA achieved to establish an energy management system and holds ISO 50001. Furthermore, E-vehicles for port logistics operations were included in strategies and an EV charging station infrastructure will be expanded (Hamburg Port Authority, n.d.)

With hundreds of companies operating in the port, Antwerp is well placed to attract recycling activities and flows of materials within circular economy. Fossil raw materials are still the main sources of feedstock for the petrochemical industry. A gradual transition to a circular economy will not only reduce the dependence on fossil materials but also contributes to boosting the competitiveness of the businesses (Port of Antwerp, 2016). The synergy between the different sectors like logistics, industrial and maritime activities introduces a multifunctional capacity which results in great added value for the Antwerp city too. From 2010, serious steps were taken to put the vision of sustainable port management practices, and giving remarkable balance between ecological and economic interests (Port of Antwerp, 2016). In 2013, the Antwerp "virtual knowledge centre" aimed to bring all innovative ideas and potential initiatives together in the Sustainable Enterprise Guide for companies. The waste management in the port of Antwerp is based on reuse or recycling. The waste which cannot be recycled is incinerated for recovery of energy, and only residues that cannot have anything else will end in landfill (Port of Antwerp, 2016). There is a strong cluster of companies that actively recycle each other's waste: one company's waste is another company's raw material feedstock, along with the industrial symbiosis concept. According to the 2015 ship management plan, ship-operators are motivated to hand over their waste by means of a refund system. It means that they must pay a flat rate charged for waste collection at the beginning, then they will be refunded by part of the payment, whenever they represent a waste declaration (Port of Antwerp, 2016).

This ensures sufficient flow of waste for collecting companies. According to a sustainability report (2016), Antwerp Port Authority supports the development of on-shore power supply by terminal operators. For seagoing ships already, there are nine onshore power take-off points in the Deurganck West terminal and four in the Deurganck East terminal. Interestingly, some empty cable conduits, cable wells, and openings have been projected and built into the quay when the new MPET terminal had been hard-surfaced so that the terminal operator can install onshore power whenever required. The port community focus is on developing the support for sustainability to all port-related companies, and absorbing sustainable financial investment. The strategy of Antwerp aims to be the main leading port in sustainable added value through collaboration between logistics, maritime section, and industry to expand new port-related services.

The circular strategies of four discussed ports have to some extent similarities, but also some differences. The differences mostly originate from the different profile of the ports. The most noticeable similarity is moving toward less dependence on fossil fuels, higher contribution of renewable energies, and optimizing waste management. Another important similarity is engagement of all stakeholders in development plans. There are similar challenges in application of the circular economy approach in these ports. Insufficient budget and allocation of sources to change the linear structure of ports for the favour of circular models, is another barrier. Ports also suffer from lack of experts, research and validated models for new circular businesses. Furthermore, in annual reports of the discussed ports, there is no clear balance in responsibilities and gains between the city and its seaport. Rotterdam and Amsterdam defined city contact points for circular ideas and activities while Hamburg has put a platform of wide information to support customers. Antwerp made a" Virtual Knowledge Centre" for innovative ideas and start-ups.

Based on documents and outlooks of the discussed ports, every port has a different solution for waste management due to the different types of industrial activities within the ports. In policies, Antwerp is leading by making clear a "0-ton residual waste” strategy. The ports of Antwerp and Amsterdam follow similar flow on providing a platform where waste can be exchanged. The port of Rotterdam reserves spots for waste companies and expands businesses while the port of Hamburg uses recovered materials in road and buildings constructions. The Port of Hamburg is the only one that has conducted a feasibility study on port-owned power plant. Compared with other ports, there is a significant attention on biofuels for transition to the bio-based circular economy in Amsterdam and Rotterdam. All the selected ports are equipped with shore power supply to vessels. Hamburg is utilizing an LNG-Powered floating power barge for cruise ships whereas land-based facilities in Antwerp are for both seagoing and inland vessels. The port of Amsterdam use shore facilities for inland vessels, at the same time as they are investigating possibilities for shore-based power for cruises as well.

In this research, it is necessary to discuss what distinguishes a self-sustainable port definition from a sustainable city-port, since there is no clear boundary to differentiate port’s sustainability apart from the urban area in particular in term of energy security. For the purpose of this research, a circular model for CMP will be introduced which will make a new definition within the energy context. It presents added value to ship-originated waste.

3. Circular economy approach for ports

3.1 Circular economy in ports, practices of EU ports

Ports city relationships have weakened recently as the port and city disintegration resulted in less direct economic benefits for cities while many environmental impacts such as air pollution still remain for local people. So, the common challenge of many port-cities is labelled the local-global mismatch (Merk, 2013). More than 90% of the indirect economic impacts of the ports of Le Havre and Hamburg are taking place in other regions than the port region itself (Merk & Dang, 2013). Ports have always played an important role in the geopolitics of Europe, as 75% of extra-EU goods and 37% of the intra-EU freight traffic are shipped through European ports (European Commission, 2016).

Through the mechanism of turning waste into resources, the ports can be more integrated into the global economy. Circular economy offers development at ports, in a more sensible approach. The port policy should match the function of the port. For example, in the Hamburg-Le Havre area, every port has a different profile, due to comparative advantages, so each port should develop its own policy along with the implementation of the circular economy (Vermeulen, 2016). There is a great deal of literature on EU ports, while the ones narrowed down to applying the circular economy approaches are limited. What is prominent in literature is the lack of description of port self-sustainability, apart from cities. If the ports are looked at as the 'matchmakers' and ‘crossing-points’ for all waste types, then it makes sense why the ports are ideal for developing the circular economy (Kyllönen, 2017). (See Figure 5).

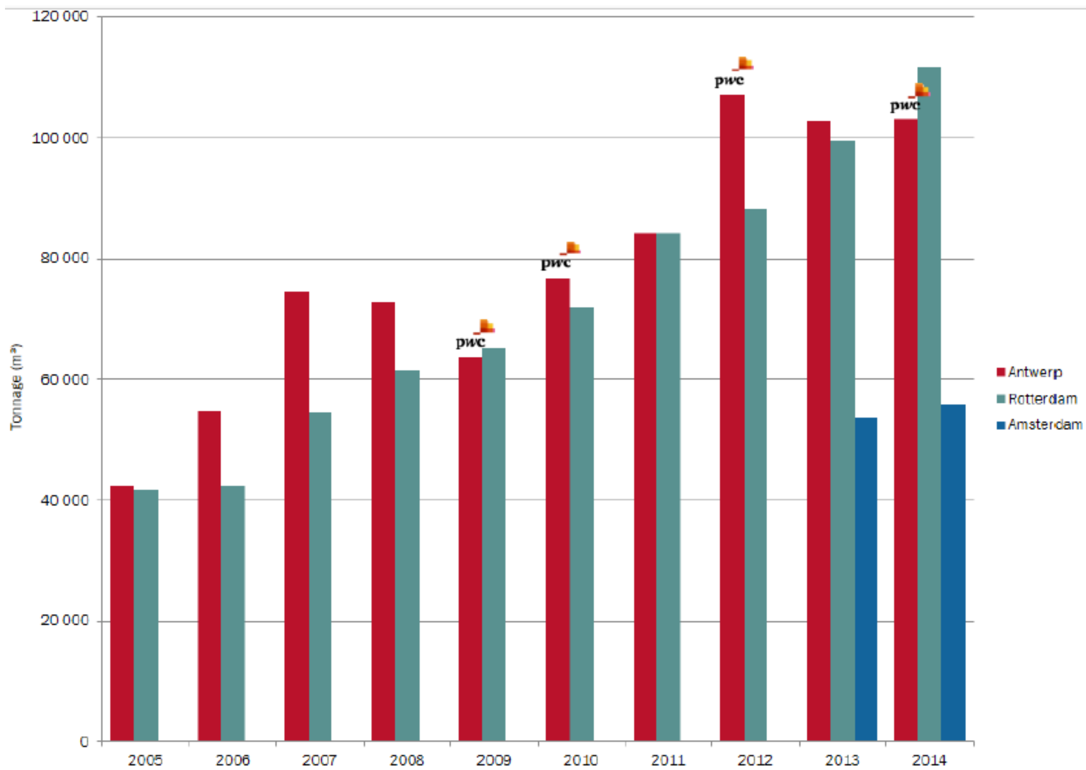


Figure 5. The comparison of the collected waste from ships for the ports of Antwerp, Rotterdam and Amsterdam,

Source: Sustainability report of port of Antwerp, (2016)

According to the he European Sea Ports Organization (ESPO), 2016 report, sustainability of the port activities is one of the top priorities in objectives of European Port Authorities. A number of EU ports are experiencing a transition to fossil fuel phase-out. To be sustainable ports, circular thinking, planning, and implementation are needed (Jansen, 2015). The transition from linear economy to circular economy is a long procedure that will need regulative and consistent support, so that the sectors such as ports can make long-term investments. EU Directive package on Circular economy notifies the importance of such an approach in all industries, including ports and the maritime industry (Bourguignon, 2016).

3.1.2 Regulations on waste management at ports

To protect the seas, MEPC 54 highlighted the importance of sufficient port reception facilities for proper implementation of the MARPOL convention toward “zero tolerance of illegal discharges from ships”. All Parties to MARPOL, are obliged to accomplish their obligations to receive ship-wastes generated during normal ship operation. A port reception facility database (PRFD) as a module of the IMO Global Integrated Shipping Information System (GISIS) was developed to allow Member States to update the Database (IMO, 2017).

EU also adopted Directive 2000/59/EC on port reception facilities for ship-generated waste and cargo residues, which aligns with MARPOL 73/78, aiming to reduce pollution from the waste produced by ships (EMSA, 2017). Currently, the European Maritime Safety Agency (EMSA) is assisting the European Commission in creating a proper information and monitoring system for framing a harmonized EU fee collection with an incentive-based waste management system, and providing elements for criteria of "green ships" and suggesting a fee reduction for vessels within this framework (EMSA, 2016).

3.2 Circular economy overview of shipping sector

The cruise shipping industry, the intersection of shipping, port and tourism industries, is strongly affecting the cities. The issues originating from this industry should be addressed at the same rate as the increase of cruise demands in the market. As cruise ports are one of the main elements of this industry, some problems of the interactions between ships and ports, such as waste management has gained more attention. Cruise tourism has become more attractive in recent decades with the help of technology advances and specialization of tourism branches. Knowing the projected significant growth in cruise shipping with consequent environmental impacts, circular economy approach can reduce externality costs on the local community. During 2003-2013 the total number of cruise ship beds increased 84.2% (Genç, 2016).

Passenger ships are subjected to uniform international standards regarding waste management under the MARPOL Convention. In some ports, they have to face additional local regulations as well. Passenger ships, due to the high number of the people on board, are one of the biggest producer of waste among different types of ships (Cruise Lines International Association, 2016). However, there are barriers to adopting a circular economy approach in general and more specific in ports. According to EllenMacArthur Foundation (2015), there are four categories of barriers. A barrier is the economic concerns of businesses assessing circular economy opportunities such as lack of capital. Another one can be classic market failure taken from standard economic theory. A third barrier is regulatory failures which are reflected in shortcomings of government policy and its implementation. Finally, there are social factors such as habits of customers and businesses.

3.3 Circular economy drivers for Copenhagen-Malmö Port

At international, and regional levels, there are regulations that can play a crucial role as the momentum to accelerate application of circular economy approaches in Copenhagen-Malmö Port (CMP) as described below.

1. The Baltic Sea is the only special area of annex IV, and discharge of ship sewage from passenger ships is forbidden unless some requirements are met. This requirement obliges the ships to have a sewage treatment plant in service with the approval of the flag state (IMO, 2017). It means that by 2021 all passenger vessels which pass the Baltic Sea, must

discharge all their sewage into port reception facilities (PRFs), or treat them with an on board system certified to meet strict requirements for nitrogen and phosphorus discharges, in accordance with the 2012 Guidelines (resolution MEPC.227(64)). For new ships built on or later than 2019, these requirements will apply earlier (HELCOM, 2016).

2. IMO limited sulphur content in fuel oil used on board ships of 0.10% m/m (mass by mass) from 2015 for Sulphur Emission Control Area (SECA) to limit the emission of SO_X and particulate matter. As approved by IMO members, the Baltic Sea and North Sea have been designated as a SECA area due to their specific environmental condition (IMO, 2017).

3. EU Directive 2014/94/EU on the deployment of alternative fuels infrastructure. Article 4: Electricity supply for transport: The Member States are obliged to ensure that the need for shore-side electricity supply is provided for seagoing ships and is assessed in their national policy. Such shore-side electricity supply has to be installed by 31 December 2025 (EU law and publications, 2014).

4. European Commission circular economy package, on 2 December 2015. The package contains an action plan for the circular economy, mapping out a series of actions planned for the coming years, as well as four legislative proposals on waste, containing targets for landfill, reuse, and recycling, to be met by 2030 (Bourguignon, 2016).

5. The Commission's 2011 White Paper on transport. It suggests that the EU's CO_2 emissions from maritime transport should be cut by at least 40% from 2005 levels by 2050, and if feasible by 50%. However, international shipping is not covered by the EU's current emissions reduction targets. In 2013, the Commission set out a strategy for

integrating maritime emissions into the EU's policy for reducing its domestic greenhouse gas emissions (European Commission, 2017).

6. Directive 2009/28/EC on the promotion of the use of energy from renewable sources. It sets a market share target of 10 % of renewables in transport fuels (Official Journal of the European Union, 2009).

7. The Energy Efficiency Directive 2012/27/EU sets up some binding measures to help boost energy efficiency. EU countries should ensure that large enterprises perform energy audits at least every four years. It identifies simple ways to reduce energy consumption and save energy. Some enterprises approach auditing scheme via energy management system ISO 50001 which put strategies in place to achieve the company’s energy saving targets (European Commission, 2016).

8. Sweden and Denmark are allowed to continue Onshore-Power-Supply(OPS) tax cuts, Directive 2003/96/EC and 2011/384/EU (European Commission, 2014).

4. Circular economy model for case study of Copenhagen-Malmö Port

4.1 Overview of the model for Copenhagen-Malmö Port

Among all shipping activities, cruise shipping is defined as “A pleasure voyage on a ship, usually with stops at various ports” (Dayioglu, 2010). Cruise shipping is in the intersection of the interest of two industries: tourism and shipping. Europe is the second biggest market with two busy cruise destinations of the Mediterranean Sea and the Northern European region. Depending on the number of passengers, Southampton, Copenhagen and Lisbon are the biggest cruise ports in order in Northern Europe (Dayioglu, 2010). A study conducted by Cruise Lines International Association(CLIA) shows that global demand for cruising has increased 68 percent in the last ten years. There is an average demand growth of 3.4 percent since 2013 (Cruise Lines International Association, 2016). Figure.6 illustrates a constant growth in the number of cruise passengers globally.

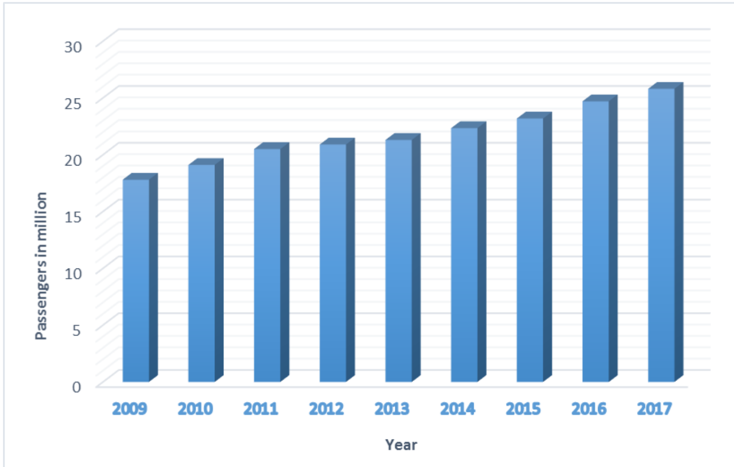


Figure 6. Global cruise passengers since 2009, with a projection for the 2017

Source: Produced by the author from Cruise Lines International Association statistics (2016)

Copenhagen-Malmö Port is located at a geopolitical position as a gateway between the North Sea and Baltic Sea, as shown in the Figure 7.

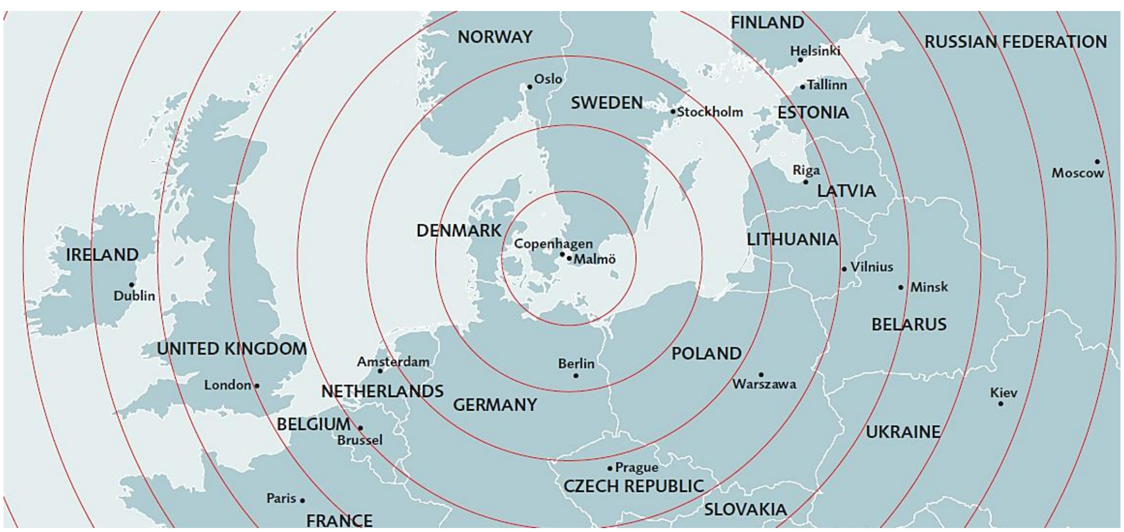


Figure 7. The geopolitics of Copenhagen-Malmo Port

Source: Copenhagen-Malmö Port annual report, (2016) It is also a major turnaround port for cruise ships where passengers either begin or terminate their cruise in the city. In this case the vessels stay longer in the port than if they were just visiting. The season for cruise shipping in Copenhagen-Malmö Port is from early May to late October (Ballini & Bozzo, 2015). From 2015, CMP has experience an increase in the number of passengers with the highest of 850,000 since 2007 as shown in Figure 8.

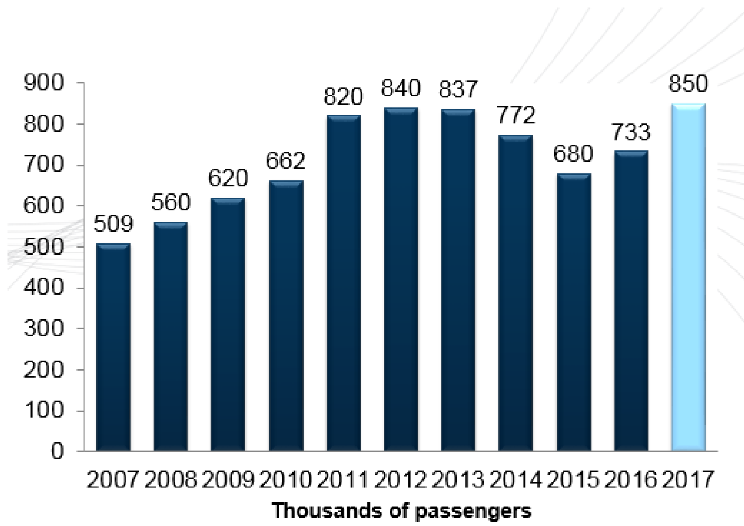


Figure 8. The number of cruise passengers in CMP

Source: Provided by the CMP through interview

To convert the threats rising from cruise shipping like air pollution and noise into the opportunities, and also to meet the environmental regulations and drivers explained in the previous chapter, a circular model for three cruise berths of Ocean quay (Oceankej in Danish language) terminal is offered in this research. The model consists of four main elements as shown in the Figure.9. They are waste management on board cruise ships, waste management in CMP port, port-owned biogas power plant, and finally Cold-Ironing to close the loop of the model. The needed technical aspects to set up such a circle will be investigated and inspected in this chapter while the cost-benefit analysis will be demonstrated in Chapter 6.

If ports can systematically be sustainable based on circular economy models, there will be not only a boost in the competitiveness but also an improvement in coastal environmental protection. Four elements of ship-waste, port waste management, biogas plant and Shore-to-Ship power supply are used to set up the model in a closed loop. Based on the model, to the port authority will take care of waste management from cruise ships to use the waste in a port-owned biogas plant. The port-owned biogas plant produces clean electricity from ship waste while to some extent contributes to port energy security. Finally, the produced clean electricity within this model will be consumed in port for shore supply to ships or for other purposes like port buildings. By this model, the ship-generated waste will be gain added value and be given back to ship in term of energy, to close the loop based on the circular economy approach.

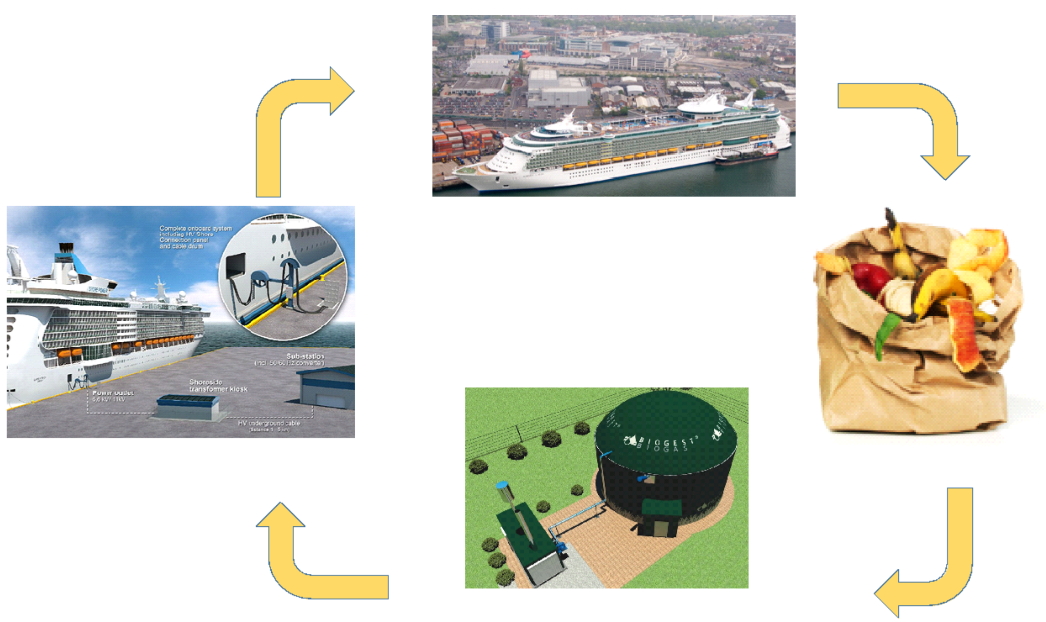


Figure 9. Circular economy model for CMP

The technical characteristics and features of models' four elements will be reviewed, and analysed independently and in relation to each other in the following sections.

4.2 Waste Management on passenger ships in the Baltic Sea

Ships produce waste from daily activities and for many years the waste generated on board has been disposed into the seas (EMSA, 2017). Different types of waste are generated such as sludge, oily-water, sewage and garbage along with cargo residues. The quality and quantity of the ship-generated waste depend on the type and size of the ship, the duration of the voyages, and importantly the waste-management on board. For example, passenger ships produce large amounts of food waste due to the high number of persons on board while the tankers' main waste is oily water from washing of crude oil tanks (EMSA, 2017). Ship discharges into the seas resulted in marine pollutions, and acidity of the ocean waters. It unfortunately has caused the death of marine life as non-digestible, non-degradable debris and plastic is eaten by marine creatures by mistake (EMSA, 2017).

United Nations adopted the Convention on the Law of the Sea (UNCLOS) which is ratified by most countries in the world, has become a local customary law, binding on the organizations, courts, and non-parties at an international level. The Convention involves the concerns of both flag states and coastal states and regulates the exploitation of the sea resources with a focus on the protection of the marine environment in Part XII (UN, 1982). IMO through the MARPOL Convention, as the main international regulatory framework, deals with prevention of pollution by ships from both operational or accidental causes (IMO, 2017). Through flag and port states, passenger ships are subjected to uniform international minimum standards in design and operation. However, they are as well under national and local regulations.

The European Directive 2000/59/EC on port reception facilities (PRF) describes the European legislation on the treatment and delivery of Ship-Generated Waste in European ports (EMSA, 2017). Passenger ships take different measures to manage garbage to meet the regulations and effective implementation of waste minimization procedures. The measures involve safe and hygienic collection, separation, and storage processes of wastes on board ships. Domestic wastes are the main part of wastes that are generated in the accommodation spaces, such as restaurants and galley, but does not include grey water (Cruise Lines International Association, 2016). Within the context of this research, only the organic domestic waste and sewage wastewater of cruise ships will be discussed.

Organic domestic waste such as solid food waste and solid combustible waste can be collected and stored on-board separately for later delivery to port reception facilities as any disposal at sea is not allowed. On the other hand, the IMO regulation in MARPOL Annex V states that garbage should be stored in such a way that does not endanger the health and safety (MEPC, 2012). Ships which generate large amount of food waste may use methods to dry it in order to reduce its volume and diminish the risk of putrefaction (Tidy Planet, 2014). The soft food waste is comminuted or grinded while adding fresh water and flushed through the piping system to a greywater sewage tank until it can be disposed at sea. Hard organic waste, ones from plates and packages are collected in bags and bins and disposed at port reception facilities (Mohammed, Torres, & Obenshain, 1998). There is no difference between cruise and cargo ships in food waste management. The only difference appears to be galley waste tank on cruise ships, which is under the same regulation as food waste. Figure 10 shows the food-waste flow on cruise ships.

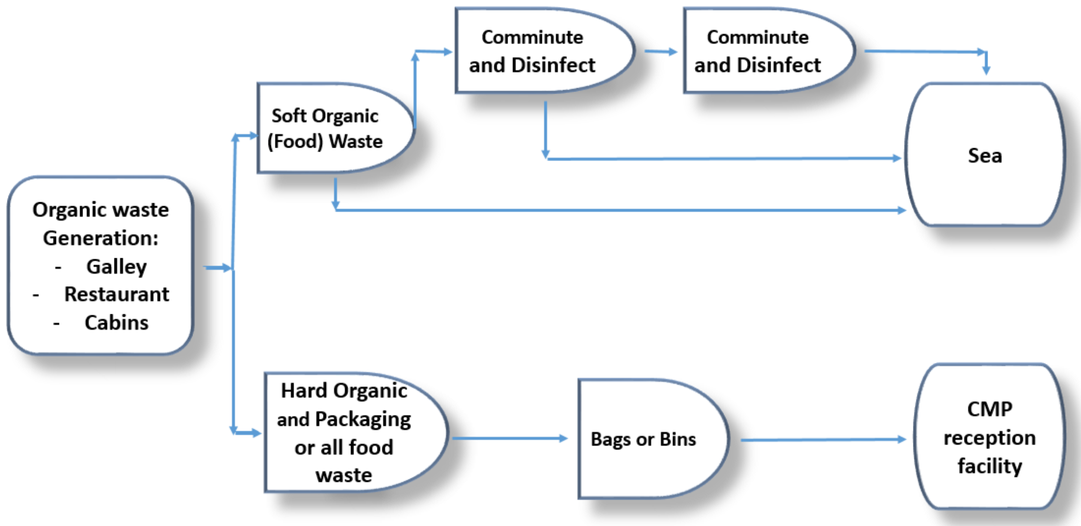


Figure 10. Flow diagram of food waste on passenger ships

On-board passenger ships, food waste are generated in the galley and restaurants. Food waste means any spoiled or unspoiled food substances and includes fruits, vegetables, dairy products, poultry, meat products and food scraps generated on board ship as defined by the IMO in revised MARPOL Annex V (MEPC, 2011). However, on-board cruise ships, a distinction is sometimes made between soft organic food waste (peels, leftovers, etc.) and hard organic (bones) and packaging (even though packaging is not food waste regarding MARPOL Annex V). This separation is based on practical management on board of ships (EMSA, 2017). Table 2 shows the discharge of the food waste under different conditions into the sea.

Table 2 Regulations on discharge of food-waste into the sea in Annex V of MARPOL

Discharge area / Garbage	Ships outside special areas	Ships within special areas
Food waste comminuted or ground	Discharge permitted ≥3 nm from the nearest land and en route	Discharge permitted ≥3 nm from the nearest land and en route
Food waste not comminuted or ground	Discharge permitted ≥12 nm from the nearest land and en route	Discharge prohibited

Source: Recaptured and reproduce from IMO Annex V by author

Through the literature and also the EMSA reports, an approximate amount of on-board food waste per person is attained, as presented in Table 3. Based on audits by EMSA, in thirteen cruise ships, food waste was managed in different ways due to difference in ship types, garbage policy, and storage capacity. It has been either comminuted, which reduces the volume, to dispose into the sea, or delivered to port reception facilities (PRF). Furthermore, the amount of food waste varied from 0.001 to 0.003 m3 per person per day (EMSA, 2017).

Table 3 Food waste estimation for cruise ships

Type of vessel	Food waste generated	Sources
Cruise ship	12 m3 of food waste per vessel per week	(EPA, 2008)
Work vessel	175 kgs/0.35 m3 of waste per week (0.3 kg per person per day)	(Tidy Planet, 2015)
Cruise ship	3.5 kg per passenger per day	(HPTI, 2007)
Cruise ship	18 to 32 kg foods and drinks per person per week	(ASCI, 2000)

Source: EMSA (2017)

Sewage

Sewage is the drainage and wastes from toilets, urinals and dispensaries. It also includes the drainage from spaces containing living animals or other waste waters when mixed with the drainages defined above. This is generally referred to as 'black water. Grey water is the drainage generated from galley basins, dishwasher, showers, laundry, bath and washbasin drains (MEPC, 2012). According to Annex IV of MARPOL, the discharge of sewage into the sea is prohibited, except when the ship has in operation an approved sewage treatment plant or when the ship is discharging comminuted and disinfected sewage using an approved system at a distance of more than three nautical miles from the nearest land. Sewage which is not comminuted or disinfected may be discharged at a distance of more than 12 nautical miles from the nearest land, and the rate of discharge of untreated sewage has to be approved by the Administration (IMO, 2017). See Figure 11.

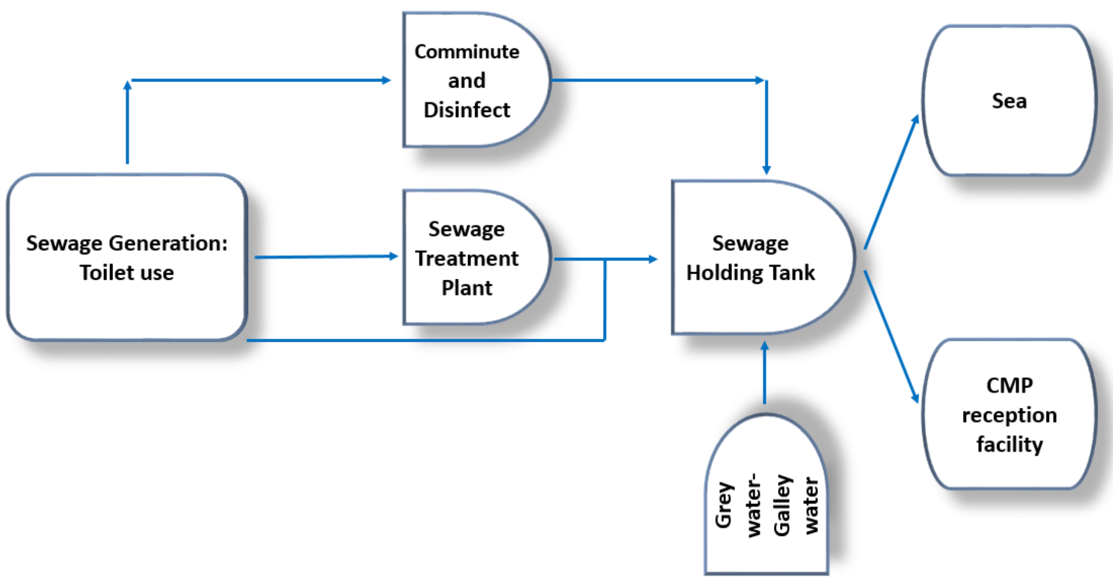


Figure 11. On-board Sewage generation flow diagram

Under Annex IV of the MARPOL Convention, the Baltic Sea area is special area. The discharge of sewage from passenger ships within the special area is generally prohibited under the new regulations, except when the ship has in operation an approved sewage treatment plant which is intended to discharge sewage effluent in special areas. According to new amendments to Annex IV by the IMO on 22 April 2016, the sewage treatment system should meet the nitrogen and phosphorus removal standard when tested for its Certificate of Type Approval by the Administration (IMO, 2017). It means that from 2019 onwards, cruise ships and passenger ferries are not permitted to discharge untreated sewage into the Baltic Sea anymore. The regulation will affect new vessels from June 2019 onwards. For those ships currently in service, they would be obliged to meet the requirements by 2021; with an exception of extension until 2023 for direct passages between St. Petersburg and the North Sea (HELCOM, 2016).

It may put financial cost on the cruising shipping companies either to equip the ships with new systems to meet regulations to discharge sewage into the sea or it can significantly increase the delivery of sewage into the port reception facilities in the Baltic ports. The latter one is more rationale since there is a fixed charge of Waste Fee as a part of the overall Port Fee, whether the ships deliver the waste or not. As shown in Figure 12, CMP is the main EU cruise destination, apart from non-EU Saint. Petersburg, in Baltic region with 323 cruise ship calls. The new regulation can considerably increase the amount of sewage delivery from cruise ships to Copenhagen-Malmö Port.

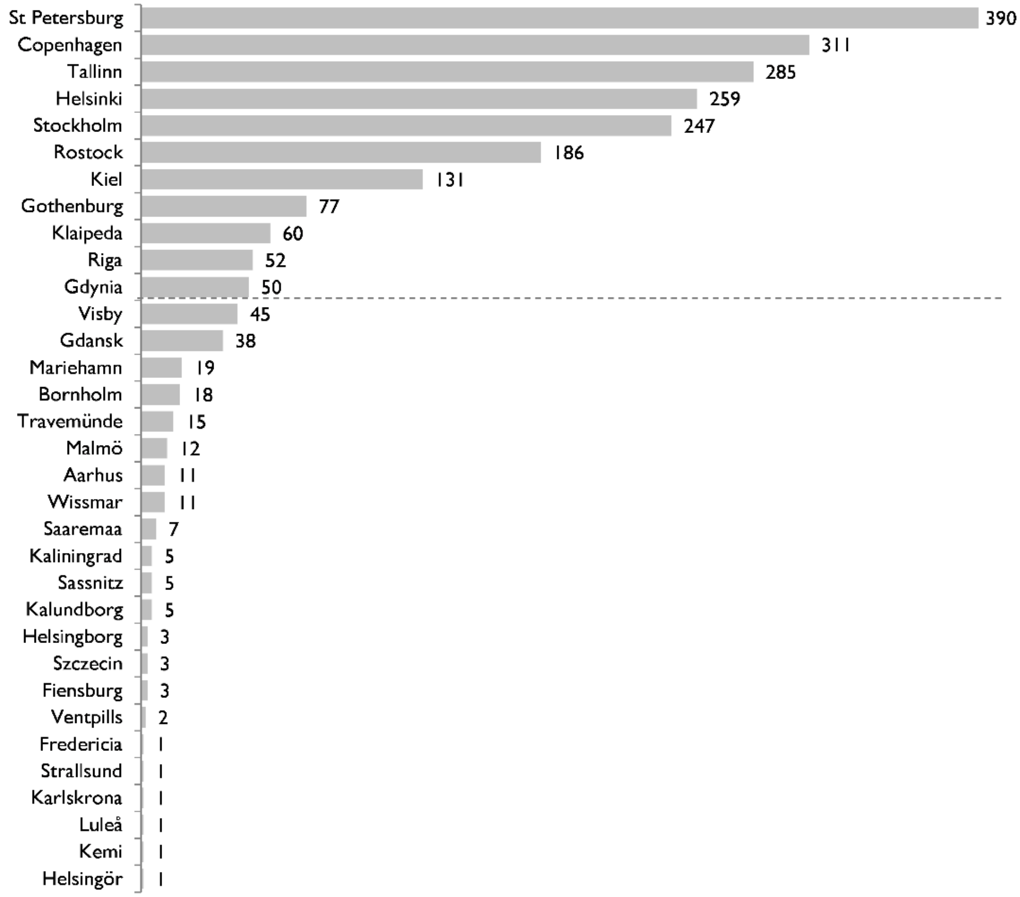


Figure 12. Baltic Sea cruise ship calls during 2014

Source: HELCOM (2015)

There are factors affecting sewage generation, like the number of persons and animals on board the vessel, number of voyage days, and the type of toilets. The water toilets produce larger amounts of sewage than vacuum toilets. The presence of a sewage treatment plant, or commuting and disinfection system provides different quantities of waste (EMSA, 2017).

Table 4 Overview of sewage per type of ships

Type of ship	Type of technology	Amount generated	Amount treated	Time period	Source
Cruise ship	Type II MSD (Marine Sewage Device) or AWTS	30,000 gallons (114 m3) per person	4,000 gallons (15 m3) of sewage sludge per day	1 week	Friends of the Earth, 2009
Cruise	AWTS	1.1-27 gallon (0.004-0.1 m3) per person	17 gallons (0.06 m3) per person	Per day	EPA, 2008
Ferries	0.1 m3 sewage per person	Per day	HELCOM, 2014	Ferries	0.1 m3 sewage per person

Source: EMSA (2017)

Table 4 (produced by EMSA in 2016), provides information about average of sewage production per person on board cruise ships and ferries. The main reason for the small number in the Table is that quantities are estimated since there are no official records or monitoring about exact amount of water consumed or from the number of days it takes for the holding tank to fill. For the same reason, there is limitation of distinguishing between sewage (black water) and other wastewaters. The amounts generated per day per person varied from 0.01 to 0.45 m3 of this quantity, 0.01-0.06 m^3 is probably black water, and the rest grey or galley water as some ships mix these two wastewaters in sewage holding tanks (EMSA, 2017).

4.3 Waste management in Copenhagen-Malmö Port

The required data about cruise ship terminal waste amount in the CMP was received by interviews in person and via email with managers of the port. Waste management in the Copenhagen-Malmö Port was carried out independently in Malmö and Copenhagen. Thus, in addition to international and EU Directives on port reception facility, the waste post-treatment is also subjected to the regulations of Sweden and Denmark. In Malmö, the port authority does not receive organic waste under the Swedish rules on organic waste origination out of Sweden. There might be smaller amounts mixed in what the ships leave as combustible. In Copenhagen, organic waste from ships is handled as combustible waste to be incinerated in power plants out of the port area. Based on interviews with the CMP, the amount of received organic wastes including both food waste and combustible materials, from passenger and cruise ships was 1086 tons during 2016.

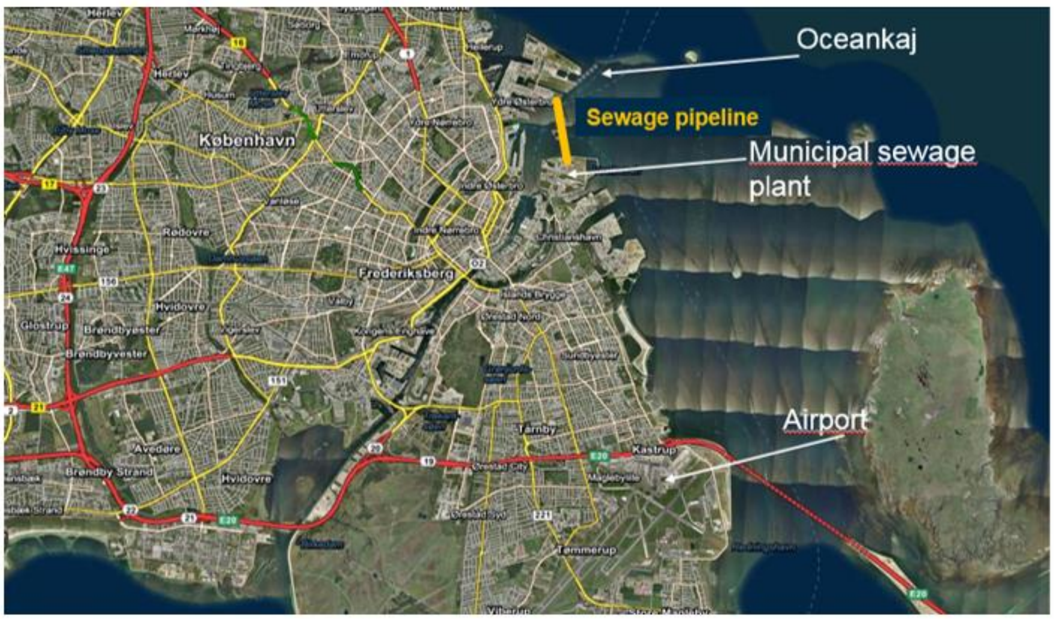


Figure 13. Cruise terminal sewage pipeline connection to Copenhagen municipality

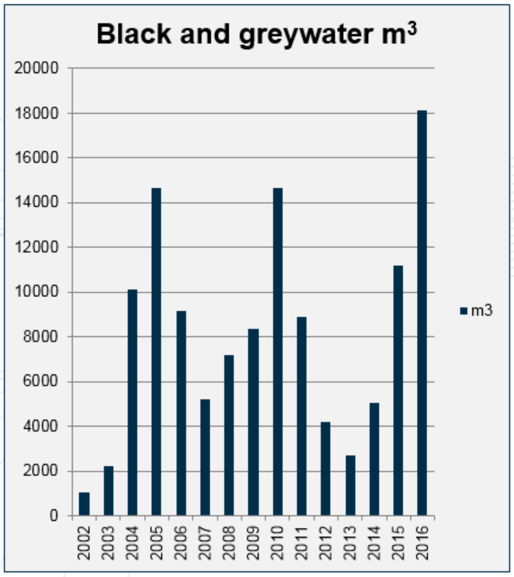
Source: Provided via interview with the CMP

Sewage is treated in different way in Malmö. The ferries (Finnlines) have been connected to the sewage pipelines to the Copenhagen municipal sewage treatment plant (MSTP). Cruise ships at Langelinie pump to tank trucks which drive to the MSTP whilst the ones at Oceankaj, pump it into a pipeline to the MSTP, as shown in the Figures 13 and 14.

Figure 14. Pipes forwarding sewage from cruise terminals to Copenhagen municipal sewage plant

Source: Provided by the CMP through interview

The amount of sewage from passenger ships in CMP during 2016, received from interviews in person with the CMP managers, 7377 M^3 (black water) and 10742 M^3 (grey water), which is altogether about 18000 $M^{3,}$ the highest since 2012 (see Figure 15). A significant increase can be seen from 2013 with 2000 M^3 to 2016 and the trend projected to be continued (CMP, 2015). New amendments on resolution MEPC.200(62) by IMO put more strict regulation on sewage nitrogen and phosphorus removal standard (IMO, 2017). From 2019 onwards, cruise ships and passenger ferries are not permitted to discharge untreated sewage into the Baltic Sea. It motivates cruise companies for delivery of sewage at CMP rather than cost to equip the ships with new standard systems to discharge sewage into the sea. Sewage port delivery is more rationale since there is a fixed charge, a waste fee as a percentage of the total port fee, whether the ships deliver the waste or not. Regarding the growth of passenger in addition to the new regulation the Copenhagen-Malmö Port as the main EU cruise destination for the Baltic region may need to deal with a significant increase in sewage reception from passenger ships in the future.



Year	m³ per ship	Dis-charges	Cruise calls	%
2010	378	38	308	12
2011	297	30	370	8
2012	189	22	375	6
~	~	~	~	~
2016	199	91	309	28

Figure 15. Wastewater reception in Port of Copenhagen

Source: Provided by the CMP through interview

4.4 Waste-to-Energy: Biogas power plant for Copenhagen-Malmö Port

Recently sustainability is at the focus of attention of environmental legislation and development. Therefore, renewables and recycling have gained significant attention. Different methods and technologies have been applied to convert waste to energy (Energen biogas, 2017). Biogas used to be applied for heating bath-water in Persia during the 16th century, and Marco Polo wrote of the use of biogas in ancient Chinese literature (Biogasplant, 2014). Food-waste, sewage slurry, manure, and by-products from forestry are potential for conversion to biogas by various techniques, such as decomposition or gasification. The Biological Anaerobic Digestion (AD) Process is one of these methods that gives a high added value to the wastes (International Gas Union, 2015). It is a series of biological processes where microorganisms break down the organic biodegradable materials, without presence of oxygen. Biogas is a high-energy methane gas and has one of the absolute lowest impacts on the environment among all fuels (IGU, 2015). (See Table 5).

Table 5 Typical composition of Biogas

Substance	Percentage %
Methane (CH_4)	50 - 75
Carbon Dioxide (CO_2)	25 - 50
Nitrogen (N_2)	0 - 10
Hydrogen (H_2)	0 - 1
Hydrogen sulfide (H_2S)	0 - 3
Oxygen (O_2)	0 - 0

Source: Figoli, Cassano, & Basile (2016)

The main product is the biogas, which can be combusted to generate clean electricity and, or to be used as biofuel in transportation. The other product of this process is slurry from the digester, which is rich in nitrogen, phosphates and potash. Since the biogas production releases useful nutrients, this is the purest form of fertilizer. The process temperature helps sterilization of the fertilizer (IGU, 2015). However, standards for organic materials that are used to enrich agricultural land is regarded in the European Directive 86/278 and regularly updated. The purpose is regulating the application of waste products as fertilisers to prevent any negative effects on soil, vegetation, animal, and human health.

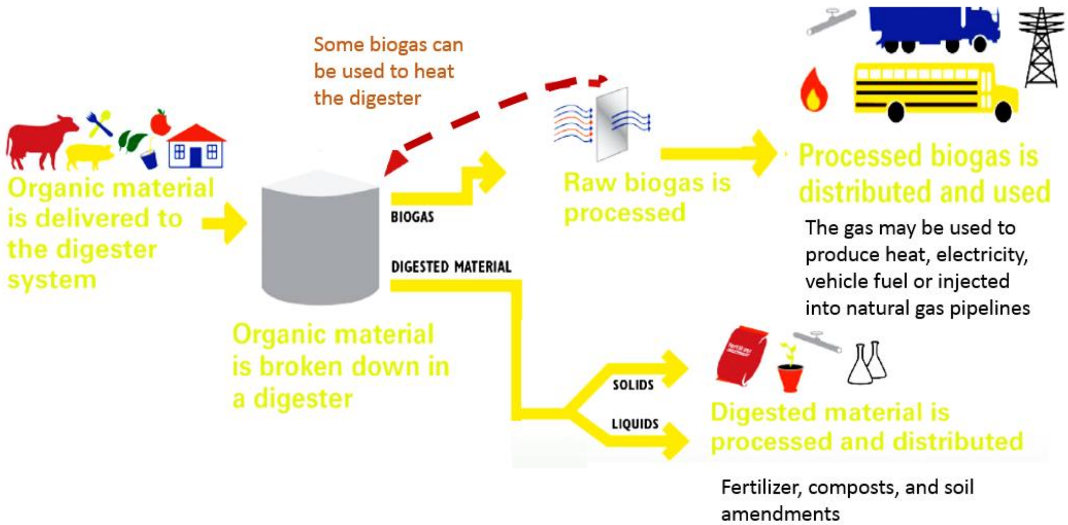


Figure 16. Process of producing biogas from organic waste like food waste

Source: Recaptured and reproduced from American biogas council (2017)

Biogas is known as a clean, and renewable source of energy, which can replace other fossil fuels to save energy in port areas (International Gas Union, 2015). In Denmark, there were 154 biogas plants in 2014 with an annual output of 1.2 TW.h and it was predicted to increase to 4.7 TW.h in 2020 by Danish Energy Agency (IEA Bioenergy, 2015). (See Table 6).

Table 6 Raw biogas production in Denmark during 2014

Substrate / Plant type	Number of plants	Production (GWh/year)
Sewage	57	250
Biowaste	-	-
Agriculture	56	861
Industrial	5	51
Lndfill	25	56
Total	**154**	**1218**

Source: IEA Bioenergy (2015)

SWOT Analysis of biogas plant in Copenhagen-Malmö Port

In an effort to better understand an investment on port-owned biogas power plant, it is useful to find the key factors that may affect the CMP's decision making. A grouping of factors can include environmental, finance, land for installation, social factors. There are drivers and barriers related to each factor that can affect the decision making, as listed in Table 7 (Vasiliki, Vasiliki, Nikolaos, & Georgios, 2012). The selected factors have been chosen according to their importance as examined during interviews with the environmental division of the CMP and also through literature. The first factor is the area for installation of a power plant. If there is not a proper location within port area for plant installation, there is the opportunity to buy land by port in another place, as stated during the interview with CMP. The social factor is affected by local municipalities and regulations. It means port development strategies are strongly influenced and linked to the city spatial planning. There is no clear policy whether to allow or to prevent the port from independently establishing a port-owned power plant. The CMP is dependent on the city grid for electricity, apart from emergency generators in the port.

Table 7 Drivers and Barriers of port-owned biogas plant in Copenhagen-Malmo Port

Factors	Barriers	Drivers
1-Land for installation	No dedicated areas allocate inside harbour area	Availability of land near to CMP port for installation
2-Social and policy factor	Not certain regulation/city policy for port-owned power plants	Public awareness
3-Finance	Uncertainty of financial support	Back-pay of investments Crowd founding mechanism
4-Environmental	Odours and small air pollution from digestion process and waste operation	Environmental benefits and meeting government fossil fuel environmental friendly targets

The finance element plays an important role in this project since with a certain annual budget and resource allocation for the port, it appears to be difficult to financially support biogas power plant installation in CMP. The last element is the environmental factor. Biogas as an energy resource produces no net production of greenhouse gases. The carbon dioxide released during biogas combustion originally is just completing a cycle from the atmosphere to plant to food waste materials and back to the atmosphere. To capture biogas as a fuel prohibits the methane release into the atmosphere. However, unfavourable odours from waste management may arise from this system (Agriculture Marketing Resource Centre, n.d.). The SWOT analysis has been applied to investigate more in-depth the different aspects of establishing a biogas plant for the port. As shown in Table 8, strengths and weaknesses are internal, which means the CMP port authority is able to influence them. On the other hand, opportunities and threats are external, meaning that the port can only react to these factors and CMP does not have any means to affect the opportunities and threats.

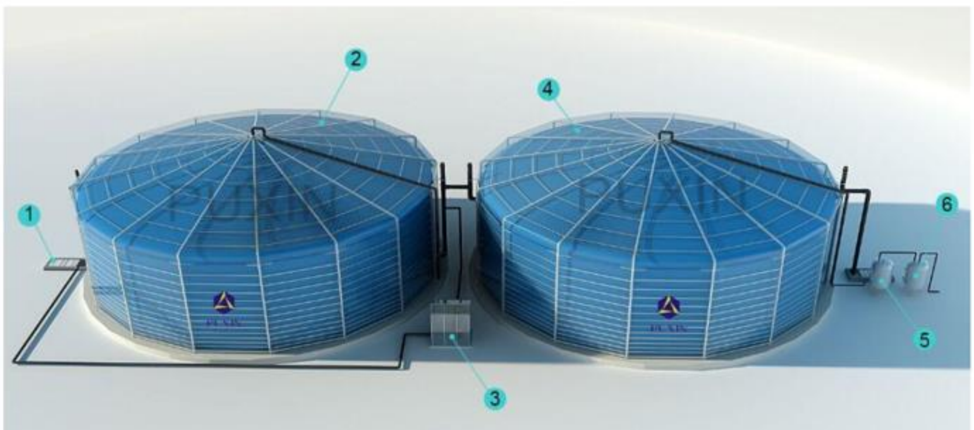
Table 8 SWOT Analysis for a port-owned biogas power plant in CMP

SWOT	Helpful	Harmful
	STRENGTHS	WEAKNESSES
Internal	1. Meeting the environmental regulations for supplying clean electricity 2. Added value to wastes and high productivity performance 3. CMP as permanent customer 4. Secured raw materials	1. Need of trained manpower and maintenance of equipment 2. Small output of produced electricity 3. Cost of funding and financing 4. full capacity running only during March to October (cruise season)
	OPPORTUNITIES	THREATS
External	1. EU Directives and national legislatives' framework and support 2. Less dependency on fossil fuels 3. Considerable biomass potentials in both Sweden and Denmark from farms and shipping activities 4. possible running on agriculture and urban household wastes	1. Possible entrance for renewable competitors in port area like wind turbines on break-waters in a few years

The main attribute which is the strength of a port-owned biogas plant is the added value to waste by producing clean energy. It also contributes to securing a part of needed electricity for port consumption. The aspects that weaken this model could be the capital and operational costs of a biogas plant. The favourable situation provided by this project will be not only meeting the regulatory framework, but also the chance of receiving financial support from the governments of Sweden or Denmark or at a higher level from the EU for investment in green energy and renewables. It allows the use of waste of other sectors like agriculture industry and municipality waste near to the port areas. The only external factor that may endanger the competitive advantage is another type of renewables such as wind turbines with lower overall cost to produce clean energy in the port area. This SWOT provides the management levels of CMP with the analysis to identify their strengths and discover new opportunities to develop appropriate strategies for both waste management and energy security.

Technical specifications of biogas power plant

Through interviews with the PUXIN Company in China, the following biogas plant offered to deal with solid organic waste.



① **Pretreatment tank** ② **First stage digester** ③ **Circulation pump** ④ **Secon**

stage digester ⑤⑥ **Biogas dehydrator and desulfurizer**

Figure 17. 3D structure of the proposed 2*260 m3 Biogas plant

Source: Puxin Co. (2017)

System Description

The medium and large size PUXIN Portable Assembly Biogas System is convenient to transport and easy to assemble. As shown in the Figure 17, it is a 2*60 m3 model assembly biogas system as proposed for the solid waste in CMP with a rate of almost 9 tons/day. It occupies an area of almost 70 M^2. It is surface mounted, except for the waste collection tank, and there is no need for digging and/or heavy construction. It can be assembled by the client itself. This system is a high efficient biogas system with hollow sunlight sheet green house and pad for insulation and heating. The heating system can use the waste heat from the electricity generator to heat the digester, and circulating pumps for raw material and anaerobic digestate mixing. (See Figure 18).

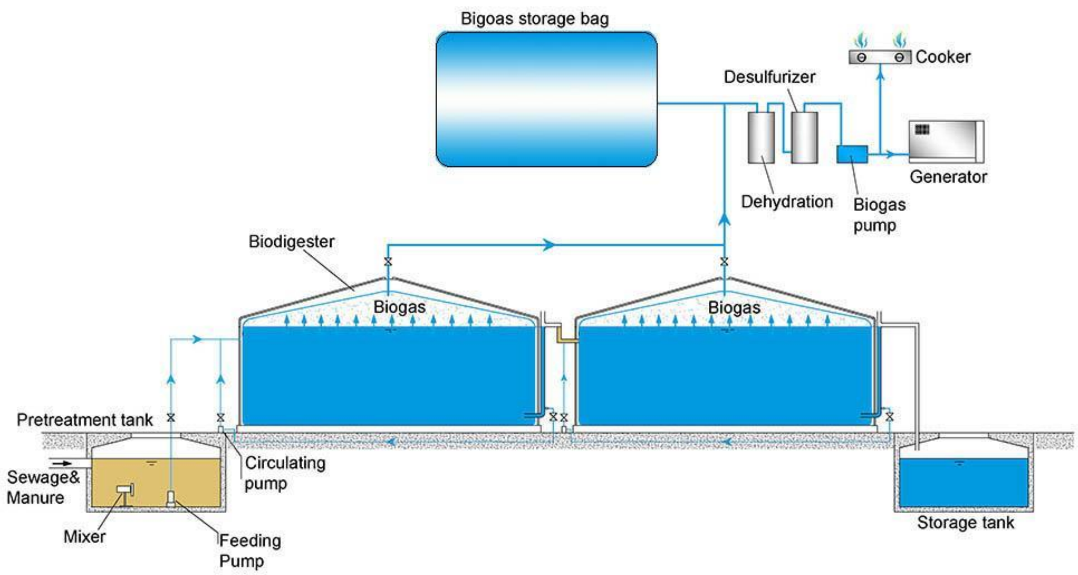


Figure 18. Plan Layout of the proposed biogas production system

Source: Puxin Company (2017)

According to the interviews with Puxin Company, the medium and large size PUXIN portable assembly biogas system is designed mainly for livestock farm manure and wastewater treatment, for slaughterhouse solid wastes and wastewater treatment, and for municipal sludge or food waste treatment. The system is mainly composed of a waste collection tank, several first stage digesters, a control room, several second stage digesters, a desulfurizing tower, and a dehydrating tower and a biogas booster pump. The digester is composed of a green house made with a hollow sunlight sheet and metal supporting frame, a membrane digester with a gas storage bag combined in one, a stainless steel sink and, a stainless steel outlet. The membrane of the digester has the characteristics of being anti-aging, acid and alkali resistant and rodent resistant. A single digester has a volume from 60 to 1000m^3. The main product of the above design will be biogas while the biogas digestate is also produced in liquid form. The latter can be used as liquid organic fertilizer for agriculture directly after mixing with water or it can be dehydrated to separate the liquid and solid to make solid organic fertilizer, the liquid can be reused to mix with new material too. (See Table 9).

Table 9 The technical specification of the biogas plant with organic solid waste as feedstock

Size of the project	• The project is designed to treat 5 tons of food waste per day
	• Biogas production will be 400 m3/d
	• Total volume of biogas digester is 400m3 (2*260M^3)
	• the fermentation capacity 135 m 3, gas storage capacity 104.8m^3
The structure and scale of project	• 2 nos. of 260m^3 assembly membrane digesters
	• 1 of 10m^3 pre-treatment tank
	• 1 of 10m^3 pre-treatment tank
	• 1 of 10m3 liquid fertilizer storage tank
	• 1 of 3000m3/d gas purify system
The construction	• The PUXIN Company design the project and sell all the products needed; provide technical support; customers install the system by themselves

Source: Produced by author from interview with Puxin Company

4.5 Cold Ironing: Technical specification of installation for Copenhagen-Malmö Port

Shore-to-ship Power (SSP) or alternative maritime power (AMP), is the process of providing shore side electrical power to a vessel at berth while its auxiliary engines are turned off. Auxiliary engines supplies continuous electrical power to lighting, emergency equipment, and communication equipment, refrigeration, and other equipment while the ship is alongside berth or is under repair at dock. It is also known as cold-ironing**.** In recent decades, with rising fuel costs and pressures to reduce shipping environmental impacts, there is uprising interest in cold ironing in ports.

EC/ISO/IEEE 80005-1:2012(E) describes standardization of high voltage systems, for both shore and on board the ship, to provide shore-to-ship electrical power. It is applicable to all the design, installation and testing of High Voltage systems. The Life cycle of the standard is every 5 years under review (International Organization for Standardization, 2013). The advantage of the international standard is harmonization of cold ironing equipment worldwide which will speed up developments by lowering costs and increasing compatibility between shore installations and ship equipment. Moreover, it extensively takes the safety of the facilities into consideration at the design stage (World Port Climate Initiative, 2017).

A state-of-the-art is that port electrification can simultaneously supply shore power to vessels and to e-mobility charging solution. The E-mobility market is growing very fast, which demands significant increase in electrical power production. The novelty of port electrification is more highlighted when the clean affordable energy is supplied to the port grids from renewable sources like green biogas power plants. This is because producing energy on shore is more efficient and cheaper than on board vessels (Bernacchi, 2017). In addition to GHG gas emission which is mainly $CO_{2,}$ running diesel engines, there are local air pollution with SOx, NOx, and Particulate Matter (PM) emissions, with direct impacts on people's health at port areas. Furthermore, there are other problems like noise and vibration which originate from running auxiliary engines of berthed cruise ships, which affect the people both on board and also in the surrounding urban area (ABB Group, 2011).

Cold Ironing also contributes to less running-hours of diesel engines. By switching off the auxiliary engines at the time of ship berthing, the operational and maintenance costs of auxiliary engines will be reduced. This is mainly due saving in fuel consumption and also less lubricating oil, and spare parts. Moreover, it reduces the workload on the technical department of the ship and give them a convenient time at ports to carry out maintenance on the diesel engines. As shown in Table 10, the air emission by auxiliary engines which are even using 0.1% low Sulphur is higher than the mixed fuel used in the EU to produce the same electrical power.

Table 10 Average emission factors for electricity production in EU and on board ships

	NO_X (g/kWh)	SO_2 (g/kWh)	PM (g/kWh)
Average emission factors for electricity production in Europe	0.35	0.46	0.03
Emission Factors from auxiliary engines using 0.1% sulphur fuel (EU 2010 limit)	11.8	0.46	0.3

Source: Ericsson & Fazlagic (2008)

Figure 19 presents the main advantages of applying cold ironing. However, despite all pros, there are a few barriers contributing to the application of this technology. The main problem pertains to the investment cost in port.

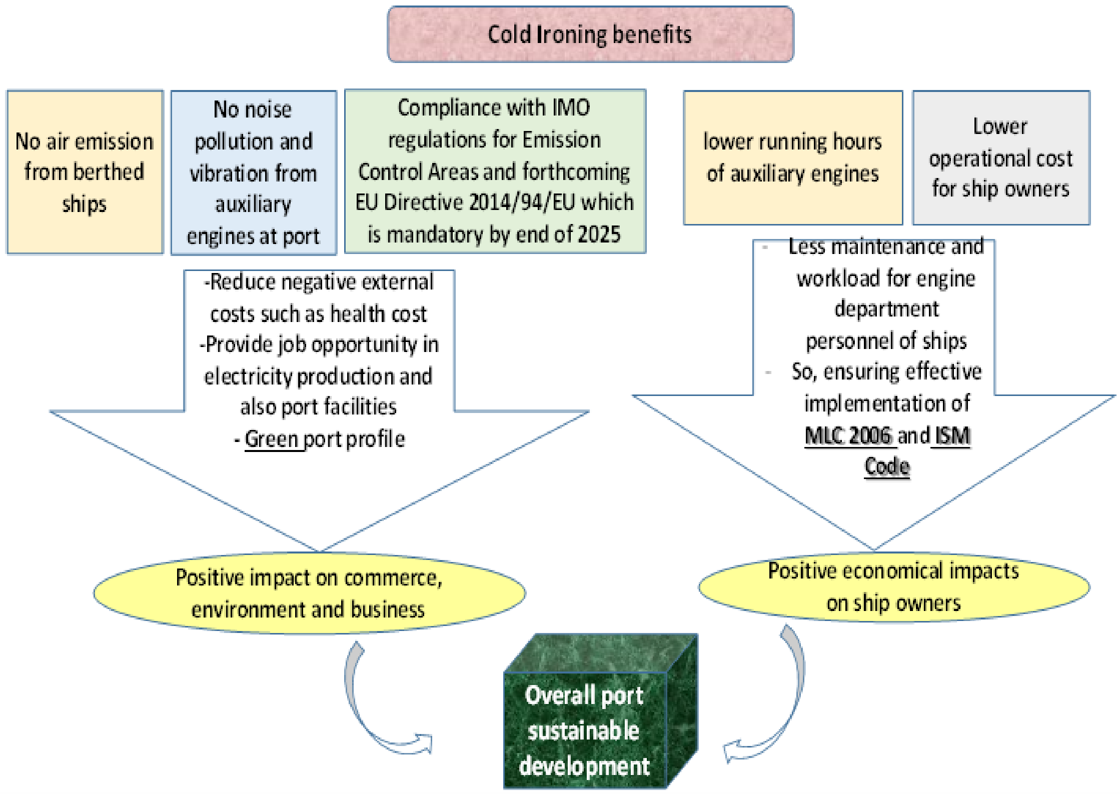


Figure 19. Cold-ironing benefits chart

The consumption of electricity will be enormous due to the demands primarily based on the type and size of the ships. Passenger ships and in particular cruise ships, require the highest amount 6.6 - 11 kV of electrical power among all ships (Bernacchi, 2017), as shown in Figure 20. In addition, the cost of retrofitting the existing passenger ships and initial cost of the cold-ironing equipment for new ships should be regarded. To assess the required cold ironing facility for Copenhagen- Malmö Port, the characteristics of the cruise ships with port calls in Copenhagen are noted. In addition, the reports of leading companies in cold ironing industries, such as the ABB Group studies on Cruise ship's electricity voltage level and frequency as shown in Figure 20, has been taken into consideration.

Characteristics	RORO/Ferry	Cruise
		
Voltage	11 kV or low voltage	6,6 & 11 kV
Max Power consumption	6,5 MVA	16/20 MVA
Frequency	60 & 50 Hz	60 mainly
Plugs/cables (per connection)	1	4+1
Transformer	onboard	onshore
Layout	Not critical	critical
Load profile	Partially controlled	Flat profile
Protect selectivity	critical	critical
Cable management system	mid cost	high cost

Figure 20. Shore-to ship power-applications and segments

Source: Reproduced from ABB group report (Bernacchi, 2017)

CMP Case Study

CMP is located in the heart of the Øresund Region with almost four million consumers. The region is experiencing increasing integration between the Danish and Swedish areas. At the same time, the region is the gateway to the entire Baltic Sea Region with more than 100 million consumers (Copenhagen-Malmö Port, 2012). CMP is a Swedish registered limited liability company. The company is a port and terminal operator in Copenhagen (Denmark) and Malmö (Sweden). The company is owned by City & Port Development I/S (50 %), City of Malmö (27 %) and various private owners with 23 % of the shares in total (Copenhagen-Malmo Port, 2015). CMP has a positive effect on the community, for example one in four tourists in Copenhagen arrives as a cruise ship guest. The cruise industry generates up to approximately 2.000 jobs in the city and a number of workplaces in the greater Copenhagen area (Copenhagen-Malmö Port, 2012). Copenhagen is by far the most popular starting point for Baltic Sea cruises, receiving over 60% of all turnarounds in the region (Copenhagen-Malmö Port, 2014). In Copenhagen there are 4 different terminal locations for up to 10 vessels. For an overview please see Figure 21.

1. Oceankaj (Ocean Quay) where the majority of Turn-Arounds are handled, Terminal 1=331, Terminal 2=332 & Terminal 3=333
2. Freeport, where some Turn-Arounds are handled.
3. Langelinie, the main pier for Port of Call.
4. Ndr. Toldbod, downtown location for smaller vessels (Copenhagen-Malmö Port, 2017).

Figure 21. Port of Copenhagen cruise terminals

Source: Provided by the CMP

Ocean Quay (or OceanKaj in Danish) as shown in Figure 21, has three cruise terminals which are used for homeporting cruise ships. According to CMP, (2015), there are two types of cruise ship visits: transit stops and turnaround stops. Transit stops are ships that dock in Copenhagen in the morning and sail in the evening without taking on any new passengers. These ships are typically berthed at Langelinie, as the passengers want to be close to the centre and no space is needed for baggage handling. Approximately 55% of the cruise ship arrivals are transit stops. Turnaround stops are the stops where passengers are replaced with new passengers. These passengers typically spend one or more nights in hotels in Copenhagen. The ships also take on more supplies. Turnaround arrivals are generally berthed at the new cruise terminals on Ocean Quay in Nordhavn, mainly because of the space needed for baggage handling. Approximately 45% of the cruise ship visits are turnaround stops that gives more time of ship-stay in Oceankej for utilization of shore power facility (CMP, 2015). Having conducted an investigation in literature and also previous feasibility studies of cold ironing for Copenhagen Ocean quay (Oceankej) cruise terminal with three berths, the required cold ironing installation components and system description for CMP are evaluated as below.

1-	Local substation	Transforms 20-100 kV electricity by the national grid to 6-20 kV
2-	Cables	Delivers the 6-20 KV power to the port terminal
3-	Frequency Convertor	To convert the 50 Hz frequency of the grid standard to 60 Hz
4-	High voltage cables	To distribute electricity to the terminal
5-	Cable reel system	For easy handling of connection of cables to the vessels. Reel is mounted on a reel tower. A davit would be used to raise the cables to the vessel.
6-	Socket	To connect both shore and ship cables
7-	Voltage Transformer	To transform electricity from high voltage to 400 V to be used for on-board power supply. The preferable location for the transformer is by the main switchboard in the engine room (Ballini, 2013).

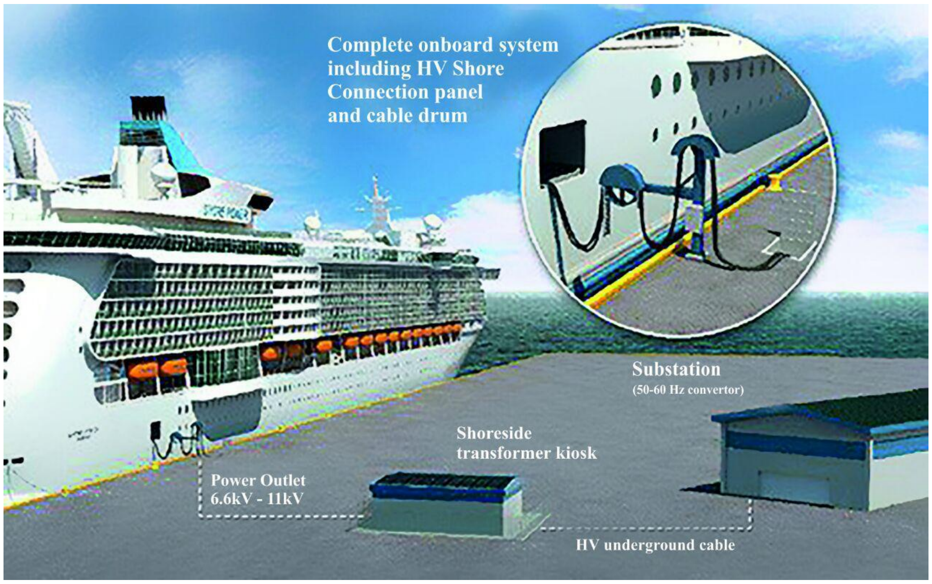


Figure 22. Suggested schematic cold ironing system

Source: Reproduced from ABB Group, (2011)

Figure 23 shows a typical shore-to-ship installation. As shown in Figure 24, the gross tonnage of the visiting cruise ships in Copenhagen during 2017 is the highest since 2007, and close to 2012. Therefore, the data which is needed for shore cold ironing facilities is extracted from a feasibility study conducted by Ballini in 2012.

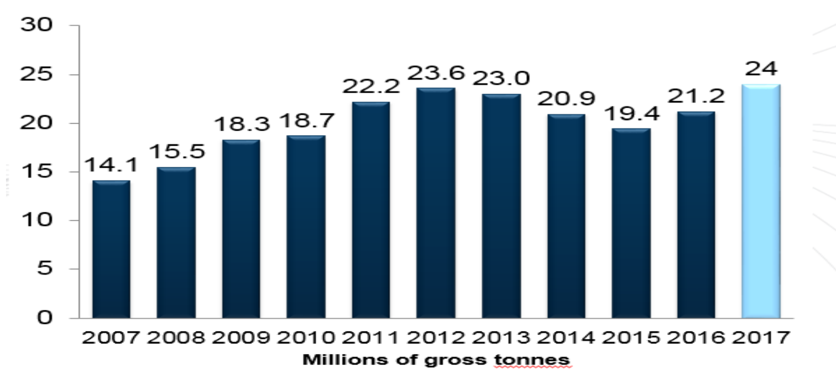


Figure 23. Gross Tonnage of visiting Cruise ships in CMP

Source: Provided by the CMP through interview

5. Cost-Benefit analysis of circular economy modelling for Copenhagen-Malmö Port

In this chapter, four scenarios will be considered for the circular model. The first scenario is the current condition of Copenhagen-Malmo Port without applying circular economy modelling. The second, third and fourth scenarios are similar in principles but the production of electricity from biogas plants are different, depending on the feedstock and consequently the capacity of suggested plants. The assumed scenarios are:

Scenario 0: Applying NO circular economy model, i.e. the current status of the port

Scenario 1: Applying circular model using cruise ship-originated organic solid wastes for the model

Scenario 2: Applying circular model using cruise ship-originated organic solid wastes and sewage waste water for the model

Scenario 3: applying circular model using organic solid wastes and sewage from all ships, the port buildings, and agriculture for the model.

In this chapter, the methodology followed for cost-benefit analysis of the model, is the calculation of all costs and benefits in paragraphs 5.1 and 5.2 for four scenarios. Primarily, a cost-benefits analysis, reflects key motives or barriers that influence the port authority's decision for the model. Furthermore, the payback time period of the whole model will be investigated in paragraph 5.3. The summary of related costs and benefits to the circular economy model, is listed in Table 11.

Table 11 Summarized costs and benefits

COSTS	Ship-generated waste management cost in CMP Port	capital and operational costs of biogas plant	capital and operational cost of Cold Ironing installation at Oceankej - Copenhagen	externality cost of berthed cruise ships in Copenhagen
BENEFITS	saving from cutting negative externality costs	saving from electrical power sale to ships	saving from waste collection in port area	saving from sale of produced fertilizer

5.1 Cost analysis in Copenhagen-Malmö Port

In this section the four costs, as listed in Table 12, for the establishment of the circular model in CMP, will be discussed and calculated.

Table 12 Costs of the model for CMP

	6.1.1	6.1.2	6.1.3	6.1.4
COSTS	Ship-generated waste management cost in CMP Port	capital and operational costs of biogas plant	capital and operational cost of Cold Ironing installation at Oceankej - Copenhagen	externality cost of berthed cruise ships in Copenhagen

The following sub-sections will calculate and critically analyse the above mentioned costs. The rate of exchange assumed 1 USD =0.837952EUR, 1USD=6.6 RMB, and 1 USD= 1 USD =6.23DKK, based on average value during September 2017 (CNN Money, 2017).

5.1.1 Cost of ship-originated waste management at CMP cruise terminals

According to interviews with the CMP cruise division, the data received on waste-management costs of CMP for 2016. (See Table 13). The first group is the waste collection service cost for only cruise terminals while the second group represents the total waste service costs for all terminals.

Table 13 Waste management costs in CMP

Waste management costs in CMP during 2016	In Danish Krone (DKK)	Euro (€)
Sewage/Sludge in Cruise terminals	1.500.000	201,414
Dry garbage in Cruise terminals	2,370,000	318,234
Total waste management costs in cruise terminals	3,870,000	519,642
Sewage/Sludge in all terminals	4,350,000	584,100
Dry garbage in all terminals	3,370,000	452,510
Total waste management costs in all terminals	7,720,000	1,036,600

Source: Provided by the CMP (2017)

For scenario 3, based on the needed electrical power in paragraph 5.1.3, the amount of input waste to the large scale biogas plant is considered 1,650 tons/day. As per interview with the Samsø biogas2020 project manager, the input of biomasses from farms will as far as possible be ‘free’, and there might be a gate fee for some (minor societal waste side-streams). This is a practice applied by most biogas plants in Denmark as stated in interviews. Therefore, there will be no payment for 1,650 tons/day feedstock to plant in scenario 3. Furthermore, to provide this large amount of free input to the biogas plant, a recommendation is offered in Chapter 7. The biogas plant operational cost will include the collection and transferring costs of the waste. Regarding the above information and following the assumed scenarios, explained in Chapter 6, the following summary has been produced.

For scenario 0: The total waste collection at cruise terminal is €519,642

For scenario 1: The waste collection at cruise terminals is 0

For scenario 2: The waste collection at cruise terminals is 0

For scenario 3: The waste collection at all terminals is 0

5.1.2 Cost of Biogas Power Plant

For scenarios 1, 2 and 3, different capacity biogas plants are offered, according to the amount of feedstock for each scenario. Initial capital costs of biogas power plants are based on interviews with biogas plant projects and manufacturers. (See Table 15). The Puxin Biogas Solution Company in China, proposed the plants for scenarios 1 and 2. The price quotations are found in Appendix B. The Puxin Company has been referenced because of the wide range of products, and reputation of projects in countries such as in France, the US and Sweden. The construction costs include the main costs for the technical equipment, while the operational costs refer to waste transportation, maintenance, and labour costs. Annual operational and maintenance (O&M) costs are in the range from 2% to 7% of initial installation costs (International Renewable Energy Agency, 2012) and in this research 4% is assumed as the operational cost of biogas plants for all scenarios. Additionally, this value is validated with Naskeo Environnement, (2017). The CMP port was interviewed for the amount of waste received from 308 visiting cruise and ferry ships in 2016. (See Table 14).

Table 14 Cruise ship-originated waste in CMP

Type of Ship-Originated Waste in CMP	Amount of Waste (m^3) or (ton)
Organic solid waste including food waste and combustible materials	1086 tons
Black water (Sewage)	7377 m3
Gray water (Sewage)	10742 m3

Source: Provided by the CMP (2017)

For Scenario 0, there is no biogas plant owned by the port currently. In scenario 1, the initial investment for producing 24/30 KW electricity is evaluated at a solid organic biomass feed rate of 9 tons/day, regarding four months of cruise shipping in CMP. The €70,909 capital cost was based on interviews with the Puxin Company. (See Table 14 and

Appendix B). In scenario 2, a higher rate of biomass is fed to produce 160/200 KW, as wastewater from cruise ships (black and grey sewage) are added to the input. In this case, the capital cost of a plant based on Puxin Company products, is €180,409. (See Table 15 and Appendix B). In scenario 3, a large amount of biomass feedstock from different sources like ships, agriculture, animal manure and household waste is considered, to produce 18MW electrical power. The maximum electricity demand of the cruise ships as discussed in section 4.5 in the previous chapter, is 16 MW. The biogas plant is assumed to be an 18 MW since 10% of the produced electricity will be consumed for the operation of the pumps, brewers, injectors in the biogas plant itself (Naskeo Environnement, 2017). For scenario 3, a biogas of 36MW, which is under construction in Denmark with an approximate capital cost of €10,750,000, is referenced, through interviews with the project manager of Biogas2020, in Samsø Municipality. Therefore, the installation cost of the 18MW plant in scenario 3 is considered €5,375,855. (See Table 15).

Table 15 Costs of different capacity of biogas plants for all scenarios

	Biogas power plant	CAPEX of biogas plant €	Annual OPEX of biogas plant	Generator Rated/Max Power (KW)	CAPEX of the matched Generator with CHP €	Annual OPEX of Generator €	Overall Cost (€)
Scenario 0	0	0	0	0	0	0	0
Scenario 1	Puxin (2*260M3)	€ 56,878	€ 2,275	24/30 kW (28/35KV.A)	€ 11,304	€ 452	€ 70,909
Scenario 2	Puxin (5*260M3)	€ 130,028	€ 5,201	160/200 KW (188/235kV.A)	€ 43,443	€ 1,737	€ 180,409
Scenario 3	--------	€ 5,375,855	€ 215,034	18 MW (21 MV.A)	-----	-----	€ 5,590,889

Assumption 2: To convert the Volt-Ampere to the Watt, the Cosφ= 0.85

Therefore, the overall costs for the establishment of different capacity biogas power plants are summarized as below:

For scenario 0: The total of biogas power plant is 0

For scenario 1: The total of biogas power plant is €71,023

For scenario 2: The total of biogas power plant is €180,842

For scenario 3: The total of biogas power plant is €5,590,889

5.1.3 Cost of Cold Ironing installation at CMP Oceankaj terminal

According to the report of Entec (2005), the initial capital cost of cold ironing infrastructure to a port varies from port to port. The major factor that affects the costs is whether the port infrastructure is to be retrofitted, or to be installed at the time of construction in a new build cruise terminal. Assuming that about 60% of cruise vessels calling on the CMP are equipped with cold-ironing facilities to use shore-power rather than electricity from the auxiliary engines of ships, it would result in a considerable health-cost benefit to local society. The 60% assumption was chosen since all the visiting cruise ships are not built or retrofitted with cold ironing equipment. In addition, to supplying electricity to all visiting cruise ships at CMP, shore-power would mean greater costs, which is out of the scope of this research (Ballini, 2013). The overall capital cost of founding a shore-to-ship power supply utility in three berths of the Oceankaj cruise terminal of the port of Copenhagen, under a feasibility study by Ballini, (2013) was evaluated to €36,866,548 as shown in Table 15. The full capacity of the offered shore-power facilities of three berths on Oceankaj, can supply electrical power for more than 60% of the visiting vessels (Ballini, 2013). Annual maintenance costs for the shore power facility itself are expected to amount to 0.8% of the construction costs per year according to the report of Copenhagen-Malmö Port, (2015), which equals €2,956,800 in scenario 3.

Table 16 Land-based cold ironing cost in Copenhagen-Oceankaj terminal

System Components for Cold Ironing installation for scenario 3	Assessed cost in Danish Krone (DKK) 2012	Cost (€)
System deliverance	160 million	21,504,000
Primary supply systems, switches, and technical room	2 million	268,800
Light building for shore power system	25 million	3,360,000
Cables, including three 20 MW cable reel tower	21 million	2,822,400
Connection fee to the utility company for 60 MV including primary plant	40 million	5,376,000
Contingencies	27 million	3,628,800
Total	275 million	36,960,000

Source: Reproduced and recaptured from Ballini, (2013)

Regarding Table 15 in section 5.1.2, the amount of the produced electricity in scenarios 1 and 2 is not enough meet the demand of cruise ships via shore-power facilities. Therefore, for these two scenarios with low electricity production in biogas plants, there will be no investment in cold ironing installation at CMP. Cold-ironing investment is assumed only for scenario 3, where sufficient amounts of feedstock to a large scale biogas plant allows production of 18MW electricity, for sale to the ships by means of cold ironing.

For scenario 0: The total cost cold ironing installation is 0

For scenario 1: The total cost cold ironing installation is 0

For scenario 2: The total cost cold ironing installation is 0

For scenario 3: The total cost cold ironing installation is €36,960,000

5.1.4 External cost of cruise ships berthing in Copenhagen

Within economics, externality is described as a cost or a benefit which is not reflected in prices in that it is incurred by a party who was not involved as either a buyer or seller of the goods or services causing the cost or the benefit. Therefore, the cost of an externality is external cost, while the benefit of an externality is external benefit (Ballini, 2013). In cruise shipping, external costs include the social cost (primarily health cost) of vibration and noise pollution, atmospheric pollution, ballast water operations, accidents, and port congestion. One way to address these externalities is to regulate the impact of the cruise shipping activities. Another way is to offer economic incentives to change behaviours like subsidizing land-based cold-ironing. A third way is to levy taxes on activities that cause external costs in order to compensate for these costs like in the Norwegian NO_X tax (Ballini, 2013). Cold ironing as an element of the proposed model for CMP creates incentives for cruise companies to choose lower price electricity over auxiliary engine (AE)-generated power.

Emission Factors

In Copenhagen-Malmö Port, the ships are obliged to a consume maximum sulphur content of 0.1% fuel or apply equivalent measure like scrubber. Therefore, emissions from this low sulphur fuel is a baseline for analysing the benefits of converting ships to use cold ironing. Using shore-to-ship electricity exempts ships from having to meet the 0.1% sulphur fuel requirement under the IMO regulations in MARPOL Annex VI for sulphur emission areas (SECA). To compare the external cost of shore-side electricity to that of 01. % sulphur fuel, the calculation of emission factors is needed (Entec, 2005).

Table 17 Emissions (g/kWh) from AE electricity in relation to emissions from the Nordic Energy Mix

Production/ Emission	CO_2 (g/kWh)	NO_X (g/kWh)	SO_2 (g/kWh)	PM (g/kWh)
Auxiliary Engines consuming 0.1% sulphur content MGO	645	13.2	0.2	0.3
Nordic Energy Mix	426	0.32	0.07	0.03

Source: Ballini & Bozzo (2013)

Table 17 indicates emissions (g/kWh) from A.E electricity in comparison to emissions from Nordic Energy Mix[1]. The total emissions of 308 port calls from the 70 cruise visiting vessels in the Port of Copenhagen during 2012 were almost 408 tons of NOx, 9 tons of SO2, and 4 tons of PM. The electricity produced from the biogas power plant in this model within scenarios 1,2 and 3, is supplied into the city grid, and then delivered to the port local grid. This is due to avoid any further cost of independent grid installation to transfer the electricity from the biogas plant to the port. In scenario 1 and 2 the electricity produced is low voltage that can be used for other purposes other than cold ironing. Although the produced electricity in these two scenarios can be used for port buildings and harbour lightings, it will not reduce the externality costs of the cruise ships at Copenhagen. Therefore, in scenarios 0,1, and 2, substantial external health costs due to the socio-economic impact of hazardous emissions from AE of cruise ships is posed to the local

[1]Total primary energy supply mix for selected Nordic countries in 2014, is 38% renewables (Weber & Smith, 2016).

people. The externality cost in this case is €5,384,086 per year (Ballini, 2013). (See Table 18).

Table 18 Total emissions and externality cost of100% of cruise ships using 0.1% sulphur MGO

100% cruise vessels at Copenhagen using A.E with 0.1% sulphur MGO	SO2	NOX	PM	CO2	Energy Demand (MWh/Year)
Emission from A.Es consuming 0.1% sulphur MGO (ton)	6 ton	418 ton	10 ton	2043 ton	31674 ton
Emission Cost using A.Es consuming 0.1% sulphur MGO (€)	€ 73,166	€ 4,569,755	€ 332,574	€ 408,591	€ 5,384,086

Source: By author, recaptured and reproduced from Ballini (2013)

In scenario 3, the produced electricity in the biogas plant is supplied to the cruise ships via land-based cold ironing installation at Oceankaj terminals. As assumed in section 5.1.3, cold-ironing installation is only for Oceankaj terminal and can cover 60% of the total cruise visits in Copenhagen. Therefore, the annual external health cost for scenario 3, is the summation of externality costs of 60% vessels using cold-ironing in berth plus the rest which is 40% using the A.E-generated electricity with 0.1% sulphur fuel. The emission factor (g/KW.h) of the produced electricity from biogas is considered the same as the figures as the Nordic Energy Mix of the grid, shown in table 17. The annual externality cost is calculated below.

Table 19 Total emission and externality cost of 100% cruise ships using AE-generated

60% cruise vessels at Copenhagen using **shore power**(based on Nordic Energy Mix)	SO2	NOX	PM	CO2	Energy Demand (MWh/Year)
Emission from 60%A.Es consuming 0.1% sulphur MGO (ton)	1.3 ton	6.1 ton	0.6 ton	8095.8 ton	19,004 MW/Year
Emission Cost using 60% A.Es consuming 0.1% sulphur MGO (€)	€ 15,363	€ 66,469	€ 19,954	€ 161,916	€ 263,702

Source: By author, recaptured and reproduced from Ballini (2013)

According to Table 19, the followings is the externality cost for scenario 3.

Externality cost of *60%* of the vessels using *shore power* (Nordic Energy Mix)

$$= \sum_{1}^{1} 1\, SOx\ cost + NOx\ cost + PM\ cost + CO2\ cost$$

= €15,365 + €66,469 + €19,954 + €161,916
= €263,702

Externality cost of *40%* of the vessels using *AE power* (0.1%sulphur)

= Externality costs of 100% cruise ships using AE power * 40%

= €5,384,086 * 40%
= €2153,634

Total Externality Cost of applying cold ironing for 60% of cruise vessels (in scenario 3)

$$= \sum \quad E.\text{cost of 60\% vessels using shore power} + \text{E. cost of 40\% vessels using AE power}$$

= €263,702 + €2,153,634
= €2,417,338

For scenario 0: The total externality costs is €5,384,086

For scenario 1: The total externality costs is €5,384,086

For scenario 2: The total externality costs is €5,384,086

For scenario 3: The total externality costs is €2,417,338

A summarized table of costs is generated, calculating the outgoing cash-flow. Furthermore, it helps to compare and analyse different capital operational costs in all scenarios. (See Table 20). The costs in all of the sections are the combination of capital costs and annual operational costs. Later in section 5.3, they will be analysed for recovery years of investments. The total costs of scenarios 0,1 and 2 are almost the same, while scenario 3 has the highest expenditure due to the initial installation costs of both a large-scale biogas plant and land-based cold-ironing.

Table 20 Summarized costs for different scenarios

Chapter 6 Costs sections	6.1.1	6.1.2		6.1.3		6.1.4	
	Cost of ship-originated waste management at CMP cruise terminal - OPEX (€)	Cost of biogas power plant+generator - CAPEX (€)	Annual maintenance and operation cost of biogas power plant+generator - OPEX (€)	Cost of initial Cold Ironing installation at CMP Oceankej - CAPEX (€)	Annual maintenance and opertationCost of cold ironing infrastructure - OPEX (€)	Annual Externality costs of cruise ships berthed in Copenhagen consuming 0.1% Sulphur - or 60% ships using cold ironing with Nordic Energy Mix-OPEX (€)	Total Cost (€)
scenario 0	€ 519,642	€ 0	€ 0	€ 0	€ 0	€ 4,944,578	€ 5,464,220
scenario 1	€ 0	€ 71,023	€ 2,818	€ 0	€ 0	€ 4,944,578	€ 5,015,601
scenario 2	€ 0	€ 180,842	€ 7,316	€ 0	€ 0	€ 4,944,578	€ 5,125,420
scenario 3	€ 0	€ 5,590,889	€ 223,636	€ 36,960,000	€ 2,956,800	€ 2,417,338	€ 44,968,227

scenario 0: applying NO circular economy model, i.e the current status without applying circular economy model to the port
scenario 1: applying ccircular model with cruise ship-originated organic solid wastes from cruise and ferry ships
scenario 2: applying ccircular model with cruise ship-originated organic solid wastes and sewage waste water from cruise and ferry ships
scenario 3: applying ccircular model with organic solid wastes and sewage from all ships, port(harbour) area, and external sources such as agriculture, and city waste.

5.2 Benefit Analysis in Copenhagen-Malmö Port

In this section the four benefits, as listed in Table 21, for the establishment of the circular model in CMP which will be discussed and calculated.

Table 21 Benefits of the model for CMP

	6.2.1	6.2.2	6.2.3	6.2.4
BENEFITS	saving from cutting negative externality costs	saving from electrical power sale to ships	saving from waste collection in port area	saving from sale of produced fertilizer

In the following sections, each of the above savings will be discussed and analysed for the model in Copenhagen-Malmö Port.

5.2.1 Savings from cutting negative externality costs

For scenarios 0, 1, and 2, since there is no cold-ironing installation, the benefits of cutting externality cost will be zero, unlike the case in scenario 3 where 60% of cruise ships visiting Copenhagen are provided with shore power in Oceankaj terminals, as in the following:

Annual Total savings if 60% of vessels use cold-ironing = (Externality cost of 60% vessels using AE power consuming 0.1%sulphur) **-** (Externality cost of 60% vessels using shore power)

To calculate the first part of the subtraction, (See Table 18), the externality cost of all ships using AE power consuming 0.1% sulphur fuel is €5,384,086. As calculated in section 5.1.4, the externality cost of 40% of the ships using AE power consuming 0.1% sulphur fuel is € 2,153,634.

Therefore, externality cost of 60% vessels using AE power using 0.1%sulphur =

(Externality cost of 100% vessels using AE power consuming 0.1% sulphur) - (Externality cost of 40% of vessels using shore power (Nordic Energy Mix)

= €5,384,086 - €2,153,634= €3,230,452

For the second part of the subtraction, as calculated already in section 5.1.4, externality cost of 60% vessels using shore power (Nordic Energy Mix) equals € 263,704.

Therefore, *Annual Total savings if 60% vessels using shore power* = € 3,230,452- € 263,704

= € 2,966,748

For scenario 0: The annual saving is 0

For scenario 1: The annual saving is 0

For scenario 2: The annual saving is 0

For scenario 3: The annual saving is €2,966,748

5.2.2 Savings from electrical power sale to ships

Electricity cost charged from city grid to port net is obtained from two different sources. The first one is the data received via interviews with the CMP, as illustrated in Table 22.

Table 22 The price of electricity charge from city grid to port

Calculation of electricity costs 1 KWh							
1/100 DKK/ kWh							
	2016	2017	2018*	2019*	2020*	2021	2022
Market price Energi Danmark	24.00	23.00	22.00	23.00	24.00	25.00	25.00
Net cost, local grid (estimated)	11.00	11.00	12.00	13.00	13.00	13.00	13.00
Net cost energinet.dk	8.33	8.43	8.53	8.63	8.73	8.83	8.93
Public Service Obligations (PSO) tariff - phased out by 2022	23.40	15.75	12.75	9.75	6.75	3.75	0.00
Total net cost	66.73	58.18	55.28	54.38	52.48	50.58	46.93
Electricity tax exclusive of minimum tax	88.10	90.60	91.60	92.60	93.60	94.60	95.60
Electricity tax - minimum tax	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Total gross excl. VAT	155.23	149.18	147.28	147.38	146.48	145.58	142.93
Elimination of electricity tax is currently being considered.							
Local grids are being studied to identify cost-cutting initiatives							

Source: Provided by CMP through interviews, (2017) Shown in Table 22, each KWh without taxation is 58.18 øre (a currency unit worth one hundredth of a Danish krone) while for sale taxation is included in the final price of 149.18 øre in 2017. This price can be used for electricity sale to the cruise ships in Copenhagen. Thereafter, the prices were validated through the report published by the Copenhagen-Malmö Port (2015), as shown in Table 23.

Table 23 Estimated electricity prices

Øre/kWh, fixed Price 2015	Public Service Obligation (PSO) levy	Electricity tax	Transport	Electricity	**Total**
2016	21.1	0.4	9.9	25.3	**56.7**
2026	21.1	0.4	9.9	46	77.4
2036	21.1	0.4	9.9	47.3	78.7
2045	21.1	0.4	9.9	47.3	78.7

Source: Copenhagen-Malmo Port, (2015)

According to Ballini, (2013) overall energy demand for cruise ships is 31,674 MWh/ year. It is used to calculate the electricity sale to only 60% of the cruise vessels which are assumed to use shore power in the Oceankaj Terminal in Copenhagen. As discussed in section 5.1.3, all ships are not supposed to be equipped with cold-ironing in addition to the assumption that land-based cold ironing is only for the Oceankaj terminal not the cruise terminals in Copenhagen.

Electricity required to 60% visiting cruise ships = 31,674 MWh/season * 60%

= 19,004 MWh/ season

Annual profit of electricity sale to 60% visiting cruise ships = 19,004 MWh * 149.18 øre/ KW.h

=28,350,167øre
=28,350,167DKK
= € 3,810,719

For scenarios 0,1 and 2, there is no cold ironing installation in the Oceankaj; therefore, there will be no electricity sale to the cruise ships. However, in scenario 1 and 2, electricity is produced in small scale port-owned biogas power plants, which can cut the costs by being used in port buildings, lightings or E-vehicles within the port area.

For scenario 1: The produced KWh during a year = 26 KW*24*365

= 227,760 KWh

The benefits of saving this electricity = 227,760 KWh * 149.18 øre/ KW.h

= 33,977,236 øre = 339,772 DKK

= € 45,613

For scenario 2: The produced KWh during a year = 180 KW * 24 * 365

= 1,576,800 KWh

The benefits of saving this electricity = 1,576,800 KWh * 149.18 øre/ KW.h

= 235,227,024 øre = 2,352,270 DKK

= € 315,852

The above calculations of savings from either electricity production or sale are summarized below.

For scenario 0: The annual saving is 0

For scenario 1: The annual saving is €45,613

For scenario 2: The annual saving is €315,852

For scenario 3: The annual saving is €3,810,719

5.2.3 Savings from waste collection in port area

To provide feedstock for the biogas plant, it is assumed that not anymore solid organic waste is collected and transported to municipality incineration plant. Hence, there will be no extra charge for this waste management and the collection cost has already been considered as a part of the annual operation and maintenance (O&M) cost of a biogas plant (Naskeo Environment, 2017). On the other hand, the sewage transfers from the cruise terminal of Oceankaj, which is connected by pipeline to the city sewage system, will not put any extra financial burden on the port's waste-management cost. Therefore, the savings from the waste management at CMP cruise terminals is equal to the cut in costs of waste collection in the cruise terminals. The cost data was provided by the CMP during interviews as per section 5.1.1, Table 13. For scenario 1 and 2, only waste management costs in cruise terminals are regarded while for scenario 3, saving of waste management from all passenger and cargo terminals is assumed.

For scenario 0: The annual saving is 0

For scenario 1: The annual saving is €519,642

For scenario 2: The annual saving is €519,642

For scenario 3: The annual saving is €1,036,600

5.2.4 Savings from selling the produced fertilizer to the agriculture industry

During biogas production from waste material, some amounts of compressed-organic waste are left over. As per interview with the Puxin Company, for each case of the solid and liquid waste materials that are fed to the biogas plant, the produced solid and liquid fertilizer will be approximately half of the input amount. However, the company stated that the amount of solid fertilizer is dependent on the percentage of the water content of the feedstock. The fertilizers can be presented in the market for sale. (See Table 24). According to Italian Biogas Association, each ton of digestate equals €13.34. This can be used to calculate the earnings from sale of digestate to the market (European Biogas Association, 2017). For scenario 1, the savings are from solid fertilizers. For scenario 2, the savings come from sale of both solid and liquid fertilizers but as the price of liquid bio-fertilizer was not applicable, only sale of solid fertilizer was regarded. For scenario 3, the same reference as in section 5.1.1 is used. The biogas plant with an approximate output of 36MW is under construction in Denmark. Therefore, the approximate 60 tons/day of feedstock is required for the model in CMP. As stated by the project manager of Biogas2020, in Samsø Municipality, the solid feedstock will be 120 tons/day. Thereafter, the produced fertilizer is assumed to be sold at a rate of 0.264 $/kg (Achinas, Achinas, & Euverink, 2017).

Table 24 Annual amount of produced fertilizer for the model in all scenarios

	Annual Feedstock (ton or m^3)	**Annual Fertilizer production** (ton or m3)	**Price per ton**	**Total Price**
Scenario 0	0	0	0	**0**
Scenario 1	1,100	550 ton	€ 13.34	**€ 7,337**
Scenario 2	1,100 ton+11,828 m3	550 ton + 5914 m3	€ 13.34	**€7,337+ N.A**
Scenario 3	600,000ton	300,000 ton	€ 13.34	**€ 4,002,000**

As the annual savings are calculated in four categories for all scenarios, the total savings of the model in scenarios 1 and 2 are almost half a million. For Scenario 3, the saving is €7,960,140. See Table 24, for the summary of all the benefits in different scenarios.

Table 25 Summarized benefits for different scenarios

	Annual saving from cutting negative externality costs	Annual saving from electrical power sale to ships	Annual savings from waste collection in port area	Annual saving from selling the produced fertilizer	Annual Total Benefit
Scenario 0	€ 0	€ 0	€ 0	€ 0	€ 0
Scenario 1	€ 0	€ 45,613	€ 519,642	€ 7,337	€ 572,592
Scenario 2	€ 0	€ 315,852	€ 519,642	€ 7,337	€ 842,831
Scenario 3	€ 2,966,748	€ 3,810,719	€ 1,036,600	€ 4,002,000	€ 11,816,067

5.3 Cost-Benefit Analysis

To calculate the time to repay the investment for the establishment of the proposed circular economy model in all scenarios, pay-back tables 26, 27, and 28 are provided which include both capital costs of installation of the biogas plant and cold ironing. Four annual saving items arising from the proposed circular economy model contributes to repay the total investments in a model lifetime of 25 years (Vasiliki et al., 2012).

In scenario 1, the savings can not cover the investment during the lifetime of the model. (See Table 26). In scenario2, though the amount of the repay is higher than the scenario 1, the initial capital costs will not be fully recovered within the defined period for the model. (See Tabel 27). In this scenario there will be a repay of 113,121,486 EUR at the end of lifetime period, without considering any discount rate. (See Table 28).

Table 26 Cost-benefit for scenario 1

Scenario 1: applying circular model with ship-originated organic solid wastes from cruise ships at CMP						
	1st Year	5th Year	10th Year	15th Year	20th Year	25th Year
Annual costs of waste management in terminals	0	0	0	0	0	0
Cost of biogas power plant installation (€) - CAPEX	€ 68,182	€ 68,182	€ 68,182	€ 68,182	€ 68,182	€ 68,182
Annual O&M Cost of biogas power plant (€) - OPEX	€ 2,727	€ 13,635	€ 27,270	€ 40,905	€ 54,540	€ 68,175
Cost of Cold Ironing installation at CMP (€) - CAPEX	€ 0	0	€ 0	€ 0	€ 0	€ 0
Annual O&M Cost of Cold Ironing installation at CMP (€) - OPEX	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0
Annual Externality costs of ships at berth	€ 4,944,587	€ 24,722,935	€ 49,445,870	€ 74,168,805	€ 98,891,740	€ 123,614,675
Total cost	€ 5,015,496	€ 24,804,752	€ 49,541,322	€ 74,277,892	€ 99,014,462	€ 123,751,032
Annual Saving from cutting negative externality costs	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0
Annual Saving from electricity sale (with taxation) to ships	€ 45,613	€ 228,065	€ 456,130	€ 684,195	€ 912,260	€ 1,140,325
Annual Saving from waste management in port area	€ 519,642	€ 2,598,210	€ 5,196,420	€ 7,794,630	€ 10,392,840	€ 12,991,050
Annual Saving from sale of produced fertilizer to the agriculture industry	€ 7,337	€ 36,685	€ 73,370	€ 110,055	€ 146,740	€ 183,425
Total benefits	€ 572,592	€ 2,862,960	€ 5,725,920	€ 8,588,880	€ 11,451,840	€ 14,314,800
payback= benefit - cost	-€ 4,442,904	-€ 21,941,792	-€ 43,815,402	-€ 65,689,012	-€ 87,562,622	-€ 109,436,232

Table 27 Cost-benefit for scenario 2

Scenario 2: applying circular model with ship-originated organic solid waste and sewage from cruise ships at						
	1st Year	5th Year	10th Year	15th Year	20th Year	25th Year
Annual costs of waste management in terminals	0	0	0	0	0	0
Cost of biogas power plant installation (€) -	€ 173,471	€ 173,471	€ 173,471	€ 173,471	€ 173,471	€ 173,471
*Annual O&M Cost of biogas power plant (€) - OPEX	€ 6,938	€ 34,690	€ 69,380	€ 104,070	€ 138,760	€ 173,450
Cost of Cold Ironing installation at CMP (€) -CAPEX	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0
Annual O&M Cost of Cold Ironing installation at CMP (€) -OPEX	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0
Annual Externality costs of ships at berth	€ 1,977,831	€ 9,889,155	€ 19,778,310	€ 29,667,465	€ 39,556,620	€ 49,445,775
Total cost	€ 2,158,240	€ 10,097,316	€ 20,021,161	€ 29,945,006	€ 39,868,851	€ 49,792,696
Annual Saving from cutting negative externality costs	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0
Annual Saving from electricity sale (with taxation) to ships	€ 315,852	€ 1,579,260	€ 3,158,520	€ 4,737,780	€ 6,317,040	€ 7,896,300
Annual Saving from waste management in port area	€ 519,642	€ 2,598,210	€ 5,196,420	€ 7,794,630	€ 10,392,840	€ 12,991,050
Annual Saving from sale of produced fertilizer to the agriculture industry	€ 7,337	€ 36,685	€ 73,370	€ 110,055	€ 146,740	€ 183,425
Total benefits	€ 842,831	€ 4,214,155	€ 8,428,310	€ 12,642,465	€ 16,856,620	€ 21,070,775
payback= benefit - cost	-€ 1,315,409	-€ 5,883,161	-€ 11,592,851	-€ 17,302,541	-€ 23,012,231	-€ 28,721,921

Table 28 Cost-benefit for scenario 3

Scenario 3: applying circular model with organic solid wastes and sewage from all ships, port area, and external sources such as agriculture, and household waste.						
	1st Year	5th Year	10th Year	15th Year	20th Year	25th Year
Annual costs of waste management in terminals	**0**	**0**	**0**	**0**	**0**	**0**
Cost of biogas power plant installation (€) - CAPEX	**€ 5,590,889**	**€ 5,590,889**	**€ 5,590,889**	**€ 5,590,889**	**€ 5,590,889**	**€ 5,590,889**
Annual O&M Cost of biogas power plant (€) - OPEX	**€ 215,034**	**€ 1,075,170**	**€ 2,150,340**	**€ 3,225,510**	**€ 4,300,680**	**€ 5,375,850**
Cost of Cold Ironing installation at CMP (€) - CAPEX	**€ 36,960,000**	**36,960,000**	**€ 36,960,000**	**€ 36,960,000**	**€ 36,960,000**	**€ 36,960,000**
Annual O&M Cost of Cold Ironing installation at CMP (€) -OPEX	**€ 2,956,800**	**€ 14,784,000**	**€ 29,568,000**	**€ 44,352,000**	**€ 59,136,000**	**€ 73,920,000**
Annual Externality costs of ships at berth	**€ 2,417,338**	**€ 12,086,690**	**€ 24,173,380**	**€ 36,260,070**	**€ 48,346,760**	**€ 60,433,450**
Total cost	**€ 48,140,061**	**€ 70,496,749**	**€ 98,442,609**	**€ 126,388,469**	**€ 154,334,329**	**€ 182,280,189**
Annual Saving from cutting negative externality costs	**€ 2,966,748**	**€ 14,833,740**	**€ 29,667,480**	**€ 44,501,220**	**€ 59,334,960**	**€ 74,168,700**
Annual Saving from electricity sale (with taxation) to ships	**€ 3,810,719**	**€ 19,053,595**	**€ 38,107,190**	**€ 57,160,785**	**€ 76,214,380**	**€ 95,267,975**
Annual Saving from waste management in port area	**€ 1,036,600**	**€ 5,183,000**	**€ 10,366,000**	**€ 15,549,000**	**€ 20,732,000**	**€ 25,915,000**
Annual Saving from sale of produced fertilizer to the agriculture industry	**€ 4,002,000**	**€ 20,010,000**	**€ 40,020,000**	**€ 60,030,000**	**€ 80,040,000**	**€ 100,050,000**
Total benefits	**€ 11,816,067**	**€ 59,080,335**	**€ 118,160,670**	**€ 177,241,005**	**€ 236,321,340**	**€ 295,401,675**
payback= benefit - cost	**-€ 36,323,994**	**-€ 11,416,414**	**€ 19,718,061**	**€ 50,852,536**	**€ 81,987,011**	**€ 113,121,486**

Table 29 Summary of paybacks for scenarios1, 2, and 3

	1st Year	5th Year	10th Year	15th Year	20th Year	25th Year
Scenario 1 payback	-€ 4,442,904	-€ 21,941,792	-€ 43,815,402	-€ 65,689,012	-€ 87,562,622	-€ 109,436,232
Scenario 2 payback	-€ 1,315,409	-€ 5,883,161	-€ 11,592,851	-€ 17,302,541	-€ 23,012,231	-€ 28,721,921
Scenario 3 payback	-€ 36,323,994	-€ 11,416,414	€ 19,718,061	€ 50,852,536	€ 81,987,011	€ 113,121,486

As shown in Table 29, there will be no payback of the investments for the circular models of scenarios 1 and 2 in CMP. However, in scenario 3, there will be a year of payback between the 5th and the 10th year that shows the feasibility of the proposed model for the scenario3.

The dynamic approach of benefits and costs, in scenario 3 with recovery year, should be considered over years. Because of the fact that the same amount of a credit can have different values depending on when the investment takes place, the net present value (NPV) is used to calculate profit by subtracting the present values (PV) of outgoing cash flows (costs) from the present values of incoming cash flows (benefits) over a period of time. According to literature, the interest rate of 8% is considered for NPV calculations (Energypedia, 2017), and defined as follows:

$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+k)^t}$$

NPV - Net Present Value

C_t - Costs in year t

B_t - Benefits in year t

k - discount rate

t - number of years from the present

n - total number of the years of the analysis period

For the 6th year NPV$= \sum_1^6 \frac{70896402-76085922}{(1+0.08)^6} = \frac{-5189520}{1.586} =$ - 272,080EUR

For the 7th year NPV$= \sum_{1}^{7} \frac{82712469-81675094}{(1+0.08)^{7}} = \frac{1037375}{1.713} = +$ 605,589EUR

Based on the above NPV calculations, the 7th year is the beginning of recovery of the investment. A cost-benefit analysis of the installation of the model for scenario 3 yielded positive net present values (NPV) at the prevailing discount rate of 8%. The results demonstrate that the establishment of the model for scenario 3 is capital intensive. However, the total cost is viable with a payback period (PBP) of 7 years.

6. Conclusion and Recommendations

Due to the world reaching planetary boundaries as a result of human activity, there is an increased awareness of the benefits of the circular economy (CE) in relation to the linear economy of most industries. The shipping sector can particularly benefit from adopting a circular economy approach not only for economic reasons but also in relation to the environmental impacts of shipping. Ports are trade gateways and therefore play an important role in the economy of countries. Therefore, a sustainable development both within shipping and port management can help reduce the negative externalities of both the shipping industry and ports and improve the environmental profile of the industry as a whole.

The CE model proposed in this research focuses on clean “waste-to-energy” technology being in line with Goal 7 of the UN Sustainable Development agenda. The research focuses on two specific targets under the Goal 7: firstly, increase the share of renewable energy and secondly upgrade technology to enable the supply of modern and sustainable energy services. Furthermore, the CE model is also relevant to Goal 13: Take urgent action to combat climate change and its impacts. In literature, four port cities Hamburg-Le Havre have been analysed that have already adopted CE approaches in their development strategies. Their strategies have similarities, but also some differences due to the different market positions and port profiles. The most noticeable similarity among the port cities is the move towards less dependence on fossil fuel and raw materials, and also to achieve a higher contribution of renewables. However, there are similar challenges in application of the circular economy approach in the port, mainly lack of budget and regulatory framework, which has been the motivation for this research.

The novelty of this research is that it is the first investigation with a focus on the application of a CE model in the port area. In this CE modelling, waste from ships will be managed by the port authority and used in the port-owned biogas plant, which attributes to added value for the waste management at the port, and boosts the port competitiveness. This research aims to assess the socio-economic benefit of the implementation of a CE model in CMP Port. The gains from a circular economy for ports is not only economic but also results in the reduction of externalities, mainly health cost for the local community in Copenhagen-Malmö.

This research is a combination of qualitative and quantitative methods used to set up the proposed model. In addition to drawing on information from literature reviews such as articles, reports and books, interviews with CMP Port managers and biogas industry have been conducted to achieve the required data. The data used in the cost-benefit analysis for the three scenarios is also used to calculate the payback of investment for the research model in CMP. When applying the CE model in relation to CMP, the payback time for the investments in scenarios 1 and 2 makes these two scenarios not economically feasible. In scenario 3, based on the NPV calculations, the recovery of investment is completed in the 7th year. A cost-benefit analysis of scenario 3 yielded a positive net present value (NPV) at the prevailing discount rate of 8% in 7 years. It means that the port will gain economic benefits in addition to improvement in energy security. Furthermore, this scenario includes port cold-ironing application which results in significant reduction in air pollution from berthed ships and consequently a substantial decrease in the externality costs, mainly health cost.

The CE model of this research involves a wide range of stakeholders such as waste management companies, biogas industry, cruise shipping cluster, local community, farmers and the municipality. In scenario 3, by managing a part of the household waste and agriculture waste by the port authority, the municipality waste-management workload is reduced. Furthermore, the proposed waste-to-energy mechanism reduces the port's electricity demand from city grid and improves the energy security of both port and the local community.

The proposed research modelling can be applied to any port around the world. Huge amounts of ship waste have been received in ports with similar geopolitics to CMP. Khorfakkan in the strait of Hurmuz in the Persian Gulf, Istanbul in Sea of Marmara, and Singapore in Malacca Strait are potential port cities which can be able to apply the model proposed in this study. The CE model can offer a unique opportunity for the CMP anchorage area as a place of waste reception from passenger and cargo ships, in addition to activates like fuel bunkering, provision of food, and logistic support.

Furthermore, to encourage shipping companies to deliver waste to CMP, it is suggested to offer a free-of-charge mechanism for those companies delivering their waste to CMP. Currently, waste charge is a 10% portion of the total port fee for ships. A ship may proceed to the next port of call without delivering the ship-generated waste if there is sufficient dedicated storage capacity on-board. Zero-charge for ship waste in the case of cruise ships will encourage vessels to deliver their waste while berthed in CMP instead of doing so at the next port of call.

Future study

Sensitive data regarding biogas power plant in scenario 3 was not commercially available for this research and some other data could not be validated through literature review. Therefore, this CE modelling for the transition of the ports into self-sustainability can be enhanced with more realistic data to be more valid. Furthermore, this research can be expanded to a multi-criteria analysis for the establishment of the CE model in ports since trade-off between conflicting aspects is inherent to the problem studied.

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Appendix. A

WORLD MARITIME UNIVERSITY

WMU Research Ethics Committee Protocol

Name of principal researcher:	Reza Karimpour
Name(s) of any co-researcher(s):	
Name of supervisor, if any:	Fabio Ballini
Title of project:	MSc Dissertation
Is the research funded externally?	Self-Funded
If so, by which agency?	
Where will the research be carried out?	WMU
How will the participants be recruited?	Individual Interviews by email in person or email
How many participants will take part?	Around 20
Will they be paid?	NO
If so, please supply details:	
How will the research data be collected (by interview, by questionnaires, etc.)?	Both questinaire and interview
How will the research data be stored?	My PC
How will the research data be disposed of?	DELETING from drive
Is a risk assessment necessary? If so, please attach	NA

Signature(s) of Researcher(s): Reza K — Date: 28.07.2017

Signature of Supervisor: — Date: 28.07.2017

Please attach:

- A copy of the research proposal
- A copy of any risk assessment
- A copy of the consent form to be given to participants
- A copy of the information sheet to be given to participants
- A copy of any item used to recruit participants

INFORMATION SHEET FOR PARTICIPANTS

Introduction

I kindly invite you to participate in this study which is exploring the Circular Economy modelling as an energy management tool for self-sustainable ports, which focuses on Copenhagen-Malmo Port as a case study. Your responses, insights and opinions would be very much appreciated as they would be vital in pointing out any shortfalls in the implementation of such an approach.

This study is in partial fulfilment of the requirements for the award of the degree of Master of Science in Maritime Affairs, specialising in Maritime Energy Management. It is anticipated that this research would provide useful information on modelling a circular economy structure for port area apart from cities and providing a way of benchmarking for other projects in the port.

Expected Participants

Selected individuals from the biogas power plant industry and port authority official managers who are involved in the relevant project(s), are expected to participate in this study.

Research Methodology

The research is being conducted using questionnaires and interviews. The questionnaire is expected to be completed in about 15 minutes, while the face-to-face interviews, which will be recorded in both writing and audio-recording, will take less than 15 minutes.

Possible Disadvantages or Risks for Participants

No known risks or disadvantages are associated with this study. All questionnaires and answers will be kept strictly confidential and anonymous.

Participation in the Research

Participants are under no obligation to take part in this research. They can withdraw at any time without giving a reason and there will be no adverse consequences in that regard.

Confidentiality

All information provided by participants will be strictly confidential. No other persons other than the researcher will have access to the data, which will be saved securely on password-protected flash drive/laptop.

Disposal of Collected Data

All data gathered in the course of interviews and administration of questionnaires during the writing of this dissertation would be disposed of after the award of the Degree. Questionnaires would be shredded and disposed of, and recordings of interviews would be deleted, and no material evidence of the actual responses would be kept for any future use.

Contact Details of Researcher:

Reza Karimpour
MSc Candidate, Maritime Energy Management
World Maritime University,
Fiskehamnsgatan 1, 21118
Malmö, Sweden
email: s17137@wmu.se
Phone: +46 728364224

Thank you for taking the time to read this Information Sheet.

INTERVIEW CONSENT FORM

This consent form outlines my rights as a participant in the study "Circular Economy approach as an energy management tool for self-sustainable ports- A case study in CMP" conducted by **Mr Reza KARIMPOUR** of the World Maritime University (WMU), Malmo, Sweden, as part of the requirements for the award of a Master of Science Degree in Maritime Affairs.

The interview will explore my insights or contributions with respect to the above mentioned topic.

It will take about 15 minutes of my time.

I understand that:

1. My participation in the study is entirely voluntary
2. I have the right/option to decline to answer any question I am not comfortable with
3. I am at liberty to end the interview at any time.
4. I may decline audio recording of this interview
5. My name and identity will remain confidential in any publications or discussions with respect to this interview
6. My name and identity will not appear on any tapes or transcripts resulting from this interview.
7. All information given by me in the course of interviews and administration of questionnaires would be disposed of after the award of the Degree.
8. All questionnaires will be shredded and disposed of, and recordings of interviews will be deleted, and no material evidence of the actual responses will be kept for any future use.

I consent to information, as outlined in the accompanying information sheet, being used for this study and other research. I understand that all information relating to volunteers is held and processed in the strictest confidence.

I have read and understood this consent form. I have had a chance to ask for clarification of any areas that i did not understand.

Signature of Interviewee

Name of Interviewee

Date

Appendix. B

SHENZHEN PUXIN TECHNOLOGY CO., LTD

PUXIN

1-2ND FLOOR , BLDG 4, MASHA XUDA HIGH TECH. INDUSTRY PARK, 49 JIAOYU NORTH RD ,
GAOQIAO DISTRICT, PINGDI STREET, LONGGANG, SHENZHEN, P.R.CHINA
TEL: +86 15675484045 WEB: http://en.puxintech.com/ Email: info5@puxintech.com

PUXIN Biogas Generation and Electricity Outpout

Green House / Others	1.2 m³	3.4 m³	15 m³	15 m³(A)	66 m³	260 m³	1380 m³
Water Level (m)	0.50	1.10	2.00	1.25	2.00	4.00	4.00
Volume of digester (m³)	0.50	1.70	13.28	8.30	54.38	200.00	800.00
Gas Storage (m³)	0.50	1.30	1.22	6.20	3.21	50.00	400.00
Biogas Production (m³/d)	0.50	2.00	15.00	8.00	50.00	200.00	800.00
Electricity (kwh/d)	0.75	3.00	22.50	12.00	75.00	300.00	1200.00

Max. Waste Treatment Capacity Per Day

Green House / Raw Material	1.2 m³	3.4 m³	15 m³	15 m³(A)	66 m³	260 m³	1380 m³
Food waste (kg)	6.25	25	187.5	100	625	2500	10000
Pig manure (kg)	11.25	45	338	180	1125	4500	18000
Cow manure (kg)	15	60	450	240	1500	6000	24000
Chicken manure (kg)	6.5	26	195	104	650	2600	10400
Human manure (kg)	8	32	240	128	800	3200	12800
Vegetable (kg)	16.25	65	488	260	1625	6500	26000
Biogas Production (m³/d)	0.5	2	15	8	50	200	800
Eletricity (kwh/d)	0.75	3	22.5	12	75	300	1200

Elnätsabonnemang för eldistribution högspänning

Ert elnätsabonnemang

Stora verksamheter har ofta ett högre effektbehov än vad som kan levereras via lågspänning på vårt lokalnät. För att tillgodose ett sådant behov finns elnätsabonnemang för eldistribution via högspänning. Kunder med denna typ av abonnemang äger sin mottagningsstation inklusive högspän- ningsställverk och transformator. Kunden har även ansvar för att elanläggningen systematiskt övervakas och kontrolleras för att uppfylla nödvändiga säkerhetskrav enligt gällande starkströmsföreskrifter.

Villkor

För detaljerade villkor, se tillämpningsvillkor och Allmänna

avtalsvillkor (NÄT 2012H rev) på eon.se.

Elnätsavgifter i område Syd
Gäller från den 1 januari 2017, tillsvidare . Avgifterna är exklusive moms.

Elnätsabonnemang: Effekt, högspänning, lokalnät	SYN20L
Anslutningsspänning (kV)	20-10
Grundavgift (kr/månad)	2 100
Effektavgift (kr/kW och månad)	64,40
Reaktiv effekt *	
- fritt uttag (%)	50
- överuttag (kr/kvar och månad)	20
Elöverföring	
- (öre/kWh)	3,99

* Reaktiv effekt mäts och debiteras för alla högspänningsabonnemang.

Beregning el-omkostning
Ved 1 KWh

Øre kWh

	2016	2017	2018*	2019*	2020*	2021	2022
Markedspris Energi Danmark	24.00	23.00	22.00	23.00	24.00	25.00	25.00
Netomkostning lokalt net (anslået)	11.00	11.00	12.00	13.00	13.00	13.00	13.00
Netomkostning energinet.dk	8.33	8.43	8.53	8.63	8.73	8.83	8.93
PSO - udfases mod 2022	23.40	15.75	12.75	9.75	6.75	3.75	0.00
I alt nettoomkostning	66.73	58.18	55.28	54.38	52.48	50.58	46.93
Elafgift ekskl. minimumsafgift	88.10	90.60	91.60	92.60	93.60	94.60	95.60
Elafgift - minimumsafgift	0.40	0.40	0.40	0.40	0.40	0.40	0.40
I alt brutto ex moms	155.23	149.18	147.28	147.38	146.48	145.58	142.93

Elafgift er pt. i vælten omkrig evt. afskaffelse.

Ligeledes kigges der på lokalt net for tiltag omkring billiggørelse

Calculation of electricity costs
1 KWh

1/100 DKK/ kWh

	2016	2017	2018*	2019*	2020*	2021	2022
Market price Energi Danmark	24.00	23.00	22.00	23.00	24.00	25.00	25.00
Net cost, local grid (estimated)	11.00	11.00	12.00	13.00	13.00	13.00	13.00
Net cost energinet.dk	8.33	8.43	8.53	8.63	8.73	8.83	8.93
Public Service Obligations (PSO) tariff - phased out by 2022	23.40	15.75	12.75	9.75	6.75	3.75	0.00
Total net cost	66.73	**58.18**	55.28	54.38	52.48	50.58	46.93
Electricity tax exclusive of minimum tax	88.10	90.60	91.60	92.60	93.60	94.60	95.60
Electricity tax - minimum tax	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Total gross excl. VAT	155.23	**149.18**	147.28	147.38	146.48	145.58	142.93

Elimination of electricity tax is currently being considered.

Local grids are being studied to identify cost-cutting initiatives

Appendix. C

SHIPS VISITING COPENAGHEN 2012 - Summer season (May- August)												
Cruise liner Vessels	Number of visit	Gross tonnage	Loa (m)	Pass do	pme kW	Match type	Voltage (Kw)	Frequency (Hz)	Time along side quay (h)	Energy consumption MW/h*	Passengers	Total passengers of all call
Emerald Princess	11	112894	289	3100	69205	DE	11		143	1001	3782	41602
Caribbean Princess	1	112894							19	133	3592	3592
Costa Fortuna	14	102587		3470					81	568	3470	48580
Grand Princess	3	107517		3300					47	329	3300	9900
Celebrity Eclipse	5	121878	304	2852	67200	DE	11		80	560	3129	15645
Azura	2	113651	289	3092	571108	DE	11		19	133	3096	6192
MSC Poesia	17	92409	294	2550	58000	DE	10		166	1159	3013	51221
MSC Magnifica	12	95128		3013					115	805	3013	36156
Costa Deliziosa	1	92720	294	2260	65000	DE	11		9	63	2826	2826
Costa Luminosa	13	97720	294	220	64000	DE	11		143	1001	2826	36738
Mein Schiff 2	4	76998	264	1922	28250	DN	7	6	40	281	2681	10724
Jewel of the Seas	8	90090	293	2110	50000	GDE	11	6	150	1048	2501	20008
Brilliance of the Seas	5	90090							53	371	2501	12505
Norwegian Sun	14	78309	259	1976	49212	DE	10	6	143	1004	2450	34300
Celebrity Constellation	6	90228	294	2044	50000	GDE	11	6	54	378	2450	14700
Vision of the Seas	6	78340	279	1998	50400	DE	7		50	350	2435	14610
Arcadia	4	83521	285	2064	51840	DE	11		34	235	2388	9552
AidaBlu	11	69203	252	2050	36000	DE	11		73	511	2192	24112
Aidasol	11	69203	251	2050	36000	DE	11		102	714	2174	23914
MSC Lirica	4	59058							35	242	2069	8276
Empress	8	48563		2020					104	725	2020	16160
Queen Victoria	2	90049	294	2014	63360	DE	11		19	133	2014	4028
Eurodam	8	86273	285	2108	64000	DE	11		79	553	2014	16112
Queen Elizabeth	2	90901							23	158	2014	4028
Aurora	3	76152	270	1878	58800	DE	7	6	28	193	1950	5850
Oriana	3	69153	260	1088	39750	DM	7	6	28	194	1928	5784
Costa neoRomantica	12	57150							109	760	1782	21384
MSC Opera	2	59058							9	63	1756	3512
Grand Mistral	12	47275	216	1196	31688	DE	7		140	978	1700	20400
Ryndam	2	55819	219	1260	34560	DE	7		20	139	1613	3226
Rotterdam	2	61849	234	1404	57600	DE	7		20	140	1404	2808
Artania	2	44588	231	1192	29160	DM	7	6	16	112	1260	2520
Marina	4	66000	252	1252	42000	DE	7	6	54	378	1260	5040
Aidacara	11	38351	193	1180	21720	DM	1	6	100	700	1230	13530
Balmoral	2	34242	188	1052	21300	DM	0	6	20	140	1230	2460
Thomson Spirit	1	33930							15	105	1224	1224
Crystal Symphony	4	50200	238	960	38880	DE	7		39	270	1010	4040
Braemar	1	19089	164	816	132	DM	0	6	10	70	929	929
Marco Polo	2	22086	176	850	15445	DM			16	112	922	1844
Costa Voyager	1	24430							10	70	836	836
Prinsendam	2	37845	204	756	21120	DM	0	6	19	133	835	1670
Ocean Princess	2	77489		824					26	182	824	1648
Ocean Countess	1	17856	164	846	15444	DM	0	6	9	63	800	800
Seven Seas Voyager	4	41500	207	706	23760	DE	7	6	53	371	730	2920
Adonia	1	30277							9	63	710	710
Discovery	2	20216	169	472	13240	DM	0	6	22	151	698	1396
Azamara Journey	2	30227							21	147	694	1388
Nautica	4	30300	181	702	19440	DE	7	6	47	330	684	2736
Columbus 2	3	30277							35	245	684	2052
Astor	1	20606	177	570	15400	DM			11	77	650	650
Black Watch	2	28668	206	828	14000	DM	0	6	24	168	589	1178
Boudicca	1	28372	206	874	14000	DM	0	6	9	63	536	536
Delphin	2	16124							21	147	470	940
Seabourn Sojourn	7	32000	198	450	23040	DE	7	6	70	491	450	3150
Quest for Adventure	2	18627							19	133	446	892
Europa	2	28437	199	408	21590	DE	7	6	22	154	408	816
Athena	2	16144	160	500	19826	DM	0	6	16	112	390	780
Silver Whisper	5	28258	186	388	15600	DM			64	445	388	1940
Kristina Katarina	1	12907	380							0	380	380
Minerva	1	12500							6	43	350	350
Fram	1	11647	114	272	7920	DE	1		9	63	328	328
Wind Surf	2	14745		312					11	78	312	624
Silver Cloud	3	16927	116						38	266	296	888
Le Boreal	3	10944	142	268	6400	DE	1		27	189	264	792
Seabourn Pride	3	9975	133	208	7280	DM	0	6	30	210	208	624

Star Flyer	6	2280		180					78	546	180	1080
Le Diamant	1	8282							8	53	165	165
Nationa lGeographic	1	6471	112	162	4708	DM	0	5 0	11	80	154	154
Clipper Odyssey	1	5218	103	120	5192	DM	0	6	7	46	128	128
Clipper Adventurer	2	5218	101	128	3496	DM	0	5	22	154	122	244
Island Sky	2	4200	91	228	3560	DM	0	6	14	95	114	228